Lab Scopes:

Introductory & Advanced

Steven McAfee

Introduction

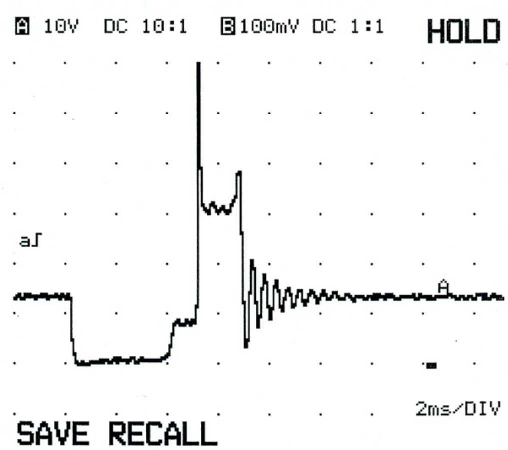
How good do you want to be at fixing cars? Just OK, so you can fix the easy ones? Or do you want to be able to figure out almost anything that comes your way? That's the edge using a lab scope can give you. Let me put it another way. If you wanted to look at something pretty, would you want an old, faded black and white photograph, or would you rather look at it with a video camera on your widescreen TV? That's what a lab scope can do for you that a scan tool can't. Oh, you need a scan tool nowadays to fix cars. But if you aren't using a lab scope, with amp probes, there's a whole world you are missing.

Without a lab scope and amp probes…there's a whole world you are missing.

This book is designed to get you into that world…

Some techs can't use a lab scope at all, and others can get a couple of patterns up on the screen. But they don't know how to make it really fly. They get nervous and confused trying to get a pattern on the screen. When it doesn't work at first, what do they do? What does the pattern mean? How do you know if the signal is good or bad? That's what this book is about. You could call this "Lab Scopes for Dummy's", except I'd probably get a call from the lawyer of the group that puts out all those books, and we don't want that.

We keep it simple. The purpose of this book is to get you measuring all kinds of things with your lab scope. And I firmly believe that if you can't make something simple when you explain it to somebody else, you don't really understand it. Later on, we'll get into some more complex applications of lab scopes. But we'll still make that simple, too. (You'd be surprised at all the testing you can do that will help you with your diagnosis.) This book is designed for the technician who doesn't really know how to use a lab scope, also called a DSO. (Digital Storage Oscilloscope) Or the tech who wants to take his diagnosis to the next level. We're going to explain these things:



- How does a lab scope work? (in very simple terms)
- When you look at a pattern on the scope, what are you seeing, and how do you know if it is bad?
- How do you get a pattern on the scope, how do you do the adjustments to make the pattern look right?
- What do you do when you can't get a pattern on the screen at all? (A lot of guys have this problem, but don't admit it to their friends…)

- What are some of the different things you can do and see with the lab scope? (Most technicians don't know how much diagnosis you can do with an inexpensive scope, and a few attachments.)
- Where and how do you hook up the scope to the circuit? Does it make much difference?

How To Read This Book—It starts simple, and gets more advanced in later chapters. You decide where you need to start. If you already know a bit about scopes, you don't need to start in the first chapter and be bored stiff. Skip ahead to what you need. That's what the table of contents is for. But I recommend you don't skip the chapter on Triggers. And if you find yourself getting lost, skip back to the simpler chapters.

We'll show some pictures, to make things simple. And please forgive my sick sense of humor, or attempts at humor. It's meant to help keep you awake. I know after a long day at work on your feet, it would be easy to just nod off. So hang on to your hats, here we go…

Lab Scopes: Introductory & Advanced

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Contents

Chapter 1

Lab Scopes - How do they work?

A lab scope draws a picture of the voltage in a circuit. And a picture is worth a thousand words. But to make sense of that, lets first compare it to a few things.

Compared to a Scan Tool: Many of you are used to working with scan tools. You pull up the data on a screen, and you read something, let's say the throttle position sensor. Maybe it says 0.6v. How quickly can that number change when the throttle changes? On many scan tools it can take a second or more, right? So, what happened in between those numbers? Did things happen that you didn't know about? That can be a problem. Some scan tools let you graph data, so you get the info updated at much quicker internals. But it still isn't as fast as you can get from a good lab scope. You could be missing something.

Scan tool data only shows what the PCM *thinks* it sees, and it doesn't update very fast.

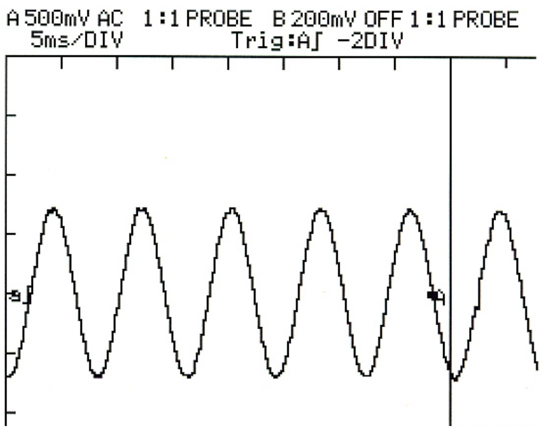
Let's think of an example. You are driving along in a Ford, you decelerate for a stoplight, and you hit a chuck hole that causes the engine to shake. This causes the TPS voltage to go below your normal 0.6v at closed throttle, down to 0.4v, just for an instant. (The TPS has started to go bad, but hasn't set a code yet.) Now the computer thinks this is your closed throttle idle position. So when the TPS is back to 0.6v at the stoplight, the computer thinks you're cruising. So it keeps the idle speed high. (It's preparing to drop the idle speed slowly for you when do your next deceleration, to keep the emissions low.) You have just duplicated the high idle problem your customer was complaining about, but will the scan tool have recorded your glitch? Probably not, with a fast glitch.

A lab scope draws a picture of the voltage...

Scan tools are quick and easy, but just beware you might not be seeing what's really going on.

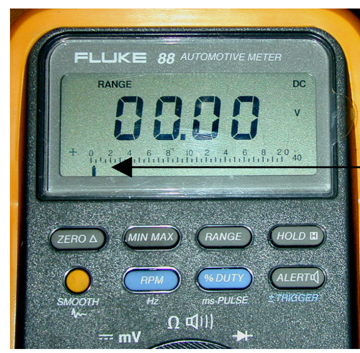
Remember, those numbers on the scan tool that just sit there and don't change don't mean the computer is seeing the same number all the time. The computer looks at the signal, then tells the scan tool what it sees. Then it looks again, and tells the scan tool what it sees. So there's this time lag between each time the number gets rewritten on the scan tool. Lots of time for there to be a glitch you don't see. And all the numbers don't go to the scan tool. Only some of them.

Another thing, with scan tools you only see the data the PCM thinks it sees, maybe not what really happened. The input data goes through a lot of steps in the computer before you see it on your scan tool. Maybe your scan tool doesn't configure something right, and you don't see the right data. Or maybe the computer has substituted a default value, but you don't know about it. Scan tools are quick and easy, but just beware you might not be seeing what's really going on.

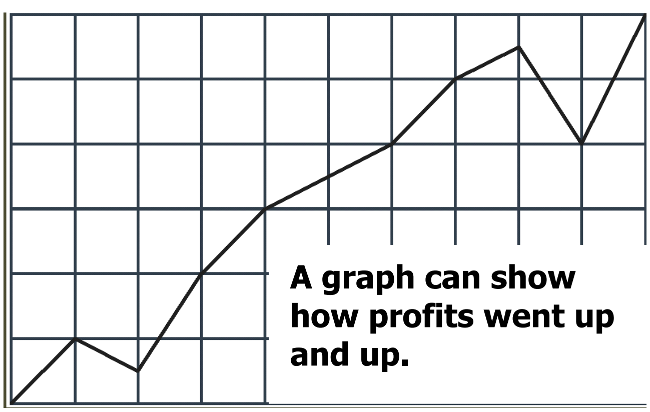


A voltmeter may not give you a complete picture of this AC signal

Compared to a Voltmeter: If you looked at that same signal with a digital voltmeter, you usually see a number on the screen. But how fast can the number change to show a glitch with the circuit? Usually only about twice a second. (Some are as fast as four updates per second.) But this is still a lot a room for error in between the number changes. If your voltmeter has an analog bar graph at the bottom, and you happen to be watching it, you are more likely to see the problem. Those bar graphs update at usually 40 or 50 times per second. That's pretty fast This would show a new reading every 25 milliseconds. (25 thousands of a second) This has a good chance of showing your problem. But you can still get more information from a lab scope.



Analog bar graph



A graph can show how profits went up and up.

What a Lab Scope Shows: The lab scope shows a picture of the voltage. It's like a graph that shows corporate profits going up or down. Like when these business types are in the board room, and somebody shows this chart with the lines sloping up, and they think they are all going to get rich. The picture shows profits spread out over time. Well, our lab scope shows a picture of the voltage over a period of time. And it can do it very quickly so you don't loose information. It can update (rate at which it takes new readings) over a million times a second.

Analog or Digital: This is something we need to understand. It will help explain why our lab scope does some of the things it does. **Analog** is when something changes gradually, or continuously. And there are no missing gaps. Like the outline of foothills that goes up and down with curves. If you want to think of something else with curves, it will give you the idea. (My wife won't let me show pictures of that here.) An analog

voltmeter is the old type that has a needle that goes back and forth. So you always get a continuous reading, and nothing gets left out. **Digital** is when you have steps, or when something is either on or off. A digital voltmeter expresses the value in a distinct number. It's either 3, or 4 (or maybe 3.14 or 3.15). It goes by steps. This comes from computer language where a value is expressed in a language of ones and zeros.

Analog Lab Scopes: These are like an old fashioned TV. They have a picture tube for the screen. And the electronics on the inside is not digital. It's continuous. The voltage goes in, gets amplified, and powers electromagnets to direct the electron beam where it should go to draw the picture. It's a continuous feed. And if the signal were to stop, the picture would stop.

Many electronics labs use the old type of analog lab scopes. They are fine when they can sit on a bench, stay plugged into the 110v outlet, and don't have to go anywhere. But they are too big to balance on a fender. And they would only have to be dropped once, and your investment would be a pile of glass pieces on the floor.

Digital Lab Scopes: These are small computer-run devices. Like the computer that runs your engine, these devices have a microprocessor inside that looks at the input signal, breaks it up into ones and zeros, and uses it's logic to figure out where to draw the line on the LCD display to represent the voltage.

Because it's digital, there will be a lag time but it can be saved, stored, and printed. Or you can take a snapshot recording.

Downside of Digital: But this means your digital scope is going to be different than your analog scope in many ways.
Notice there was thinking going on inside it's little brain. And just like you or me, this thinking takes some time. So there is always a time lag from when the signal occurred, to when the picture gets drawn on the screen. Expect that, like death and taxes, it's just going to happen.

Also, the brain is deciding which part of the screen to light up. The screen is made of pixels, and these are only so small. So sometimes you don't get quite as much definition as you would like because the pixels aren't small enough to make a really good picture. Think of a four year old making a face with blocks. It might not have all the details of a good camera picture. But you could drop this LCD screen, and it usually survives just fine. Mine always has. And it's small enough to balance on lots of things in the engine compartment.

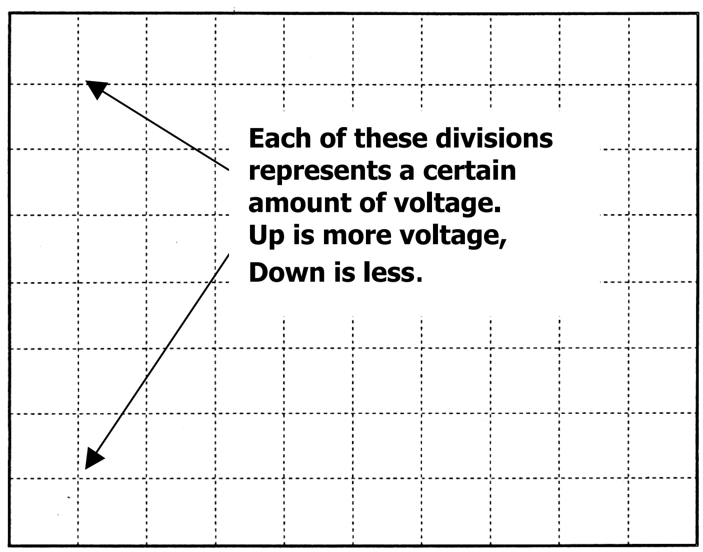
Advantages of Digital: But there's an up side to this brain thing too. Because the signal was broken down into ones and zeros (digitized), it can be stored. This is cool. You can save a memory of a pattern, upload it to your computer, print it out, and show it to the customer or file it away in your own library. This digital concept also means you can have a record feature like many scan tools. You could drive a vehicle until it acts up, push a button, and come back to the shop and view a recording of when the signal went bad, and what it looked like. You can't do that with an analog scope because there is no computer inside.

Introduction to a Basic Model: Comb your hair and put on a clean shirt. "What for?" you are saying. You are about to get introduced to a model. Well maybe this model isn't blonde with long legs, but this model is still very important to you. I'm going to show you the basic screen on my model of lab scope. There are some basic things about the lab scope screen (called a desktop on a computer) that you should know. They may look different on different scopes, but many of the basic parts will be there, whatever model you have. You need to know this if you are going to understand what you're looking at.

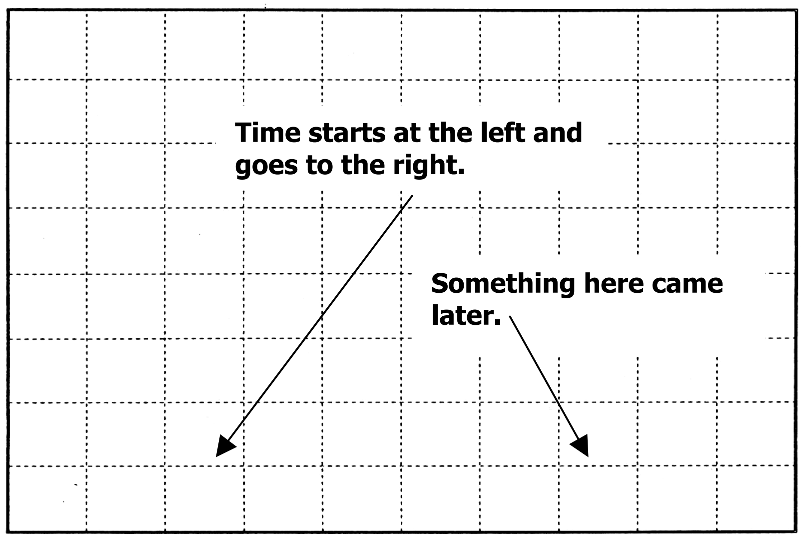
Divisions or Graticules: Let's start by looking at a blank screen. This lab scope screen is divided up into divisions or graticules. Kind of like a city is divided into blocks by different streets, or a map has lines of longitude and latitude on it. And these divisions are there, even if you don't see them on some scopes. (Sometimes we blank them out because they get in the way.) Often you will see notches at the edges of the screen to see that the divisions are still there. We use these divisions to show more or less of something, so you know how much you are looking at. Many times you won't see a number. You are just going to see a line that draws on the screen to make a picture. We call this picture the trace, or pattern, or waveform. There's no law that says what we have to call it, so different people call it different things.

Voltage: Voltage is shown by going up and down on the screen. As we go up we show more voltage, as we go down, we show less. You could think of a ruler. The further out you go, the more inches you have.

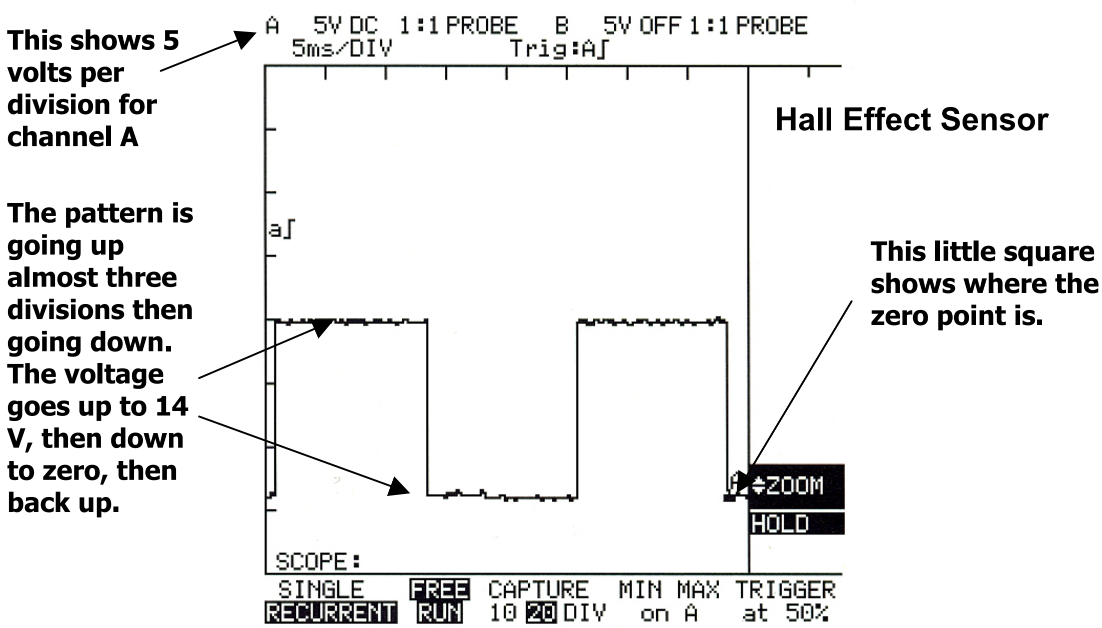
For example, if each division was one volt, then if we go up five divisions, we went up five volts. If we went up 1 1/2 divisions, we would be showing 1 1/2 volts. We could make each division be 0.1 volts, or maybe 100 volts. It's very adjustable.



Time: As we are looking at a picture of voltage, we need to remember that this picture has taken place over a period of time. Each lab scope screen shows a slice of time. As the divisions go from left to right, we show the time when something happened. The part of the line on the left happened before the part on the right. And we have to know **how much time** this is, for the pattern to make any sense. This time may be shown as time per division, or as time over the whole range of the screen. It's another one of the things we look at right away when we first see a pattern

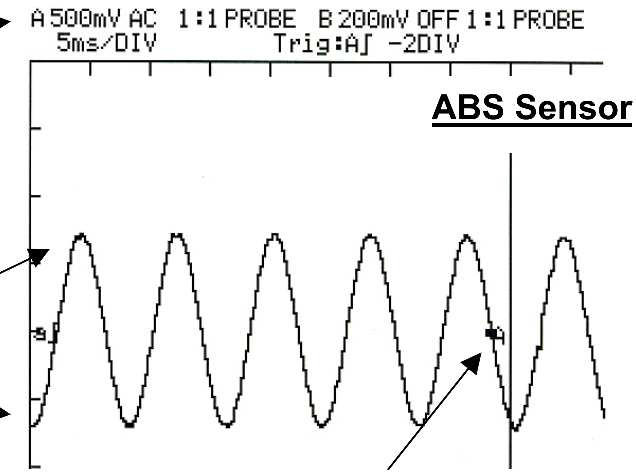


When you first look at a pattern, you need to look for the numbers that show **how much voltage** and **how much time** are we looking at on the screen. We have a lot of flexibility here. This can be shown as voltage per division, or voltage over a whole range or the whole screen. The same with time. How these numbers are set makes a big difference in what we see.



Zero point: Another thing to look at is our zero point. (Sometimes called the ground point.) It will be shown with different symbols on different scopes. This is where the zero amount of voltage would be. This is also adjustable, and may be in different places on the screen, depending on what we are looking at. We might have the zero point near the bottom, because we're looking at positive DC (direct current) voltage. And this will be all above the zero. Or we might have the zero point in the middle, because we're looking at AC (alternating current) waveform of an ABS signal. And with AC, half the signal may be above the zero, and half the signal below the zero.

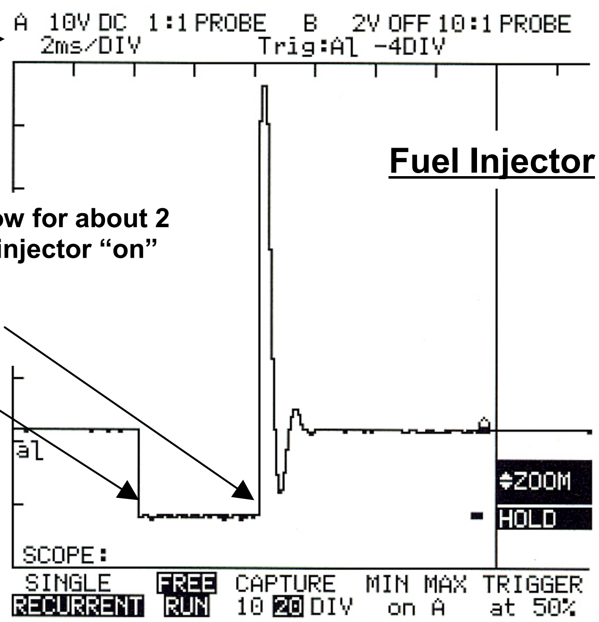
This shows the voltage level of 500mV per division for Channel A. (The AC means we will see only AC voltage. More on that later.)



The voltage went up to about 700 mV and down to about –700 mV, for a peak to peak voltage of 1400 mV, or 1.4 VAC.

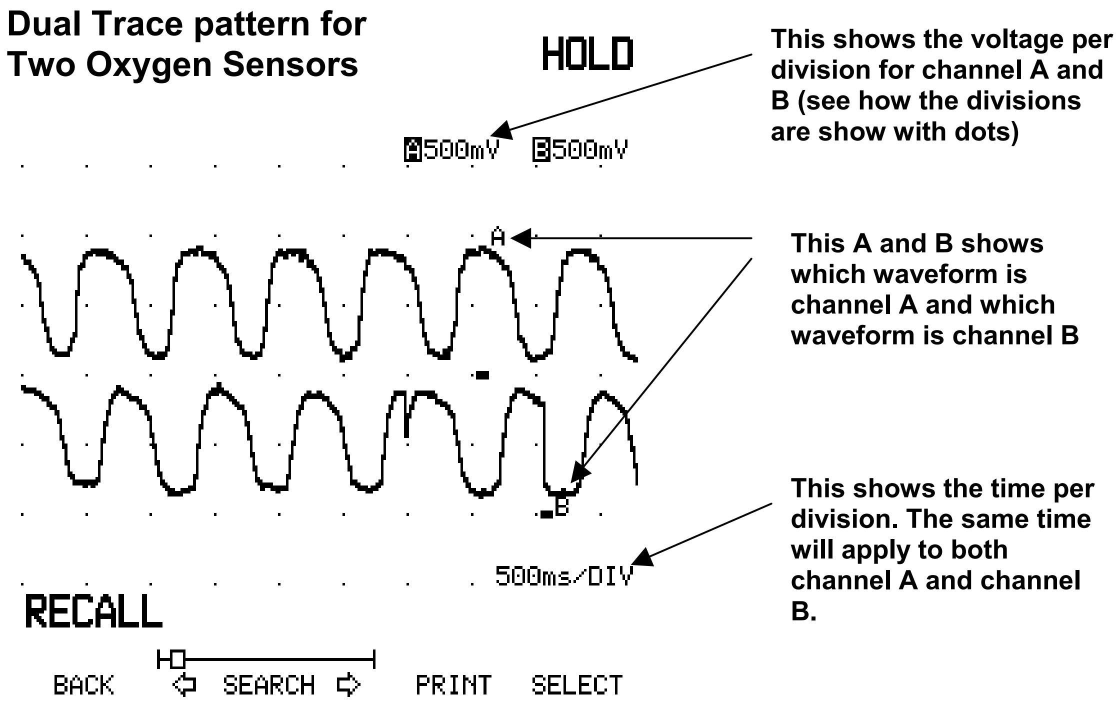
This little square shows where the zero point is. It's in the middle for AC.

This "2ms" shows the time for each division. (2ms is two thousands of a second)



The voltage goes low for about 2 divisions. The fuel injector "on" time is about 4ms. From here to here:

Channels: Most Lab Scopes can draw a pattern for more than one signal at a time. Two is the most common, some expensive ones can do four. Each signal comes into the scope on a different wire; we call these “channels”. (Like the different channels on your TV set.) There will be some letters or numbers on the screen to show which waveform is from which channel. You might see channel A and channel B, or sometimes channel 1 and channel 2.

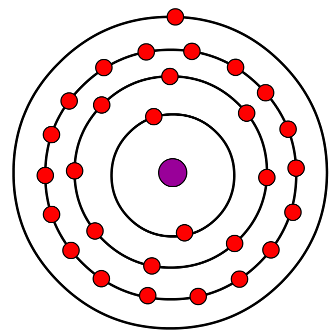


Chapter 2

Basic Electricity, Circuits and Digital Signals

Let’s be honest; how many of you really understand electricity? But if we are going to understand what we are measuring, we’d better understand it. And we need to understand the types of digital signals we will be seeing, so we know what is good or bad when we see the pattern. So that’s what we are going to cover in this chapter. If you are an electrical engineer, you can skip this chapter…

What is Electricity? This is real simple. The movement of electrons. (Preferably in a controlled circuit.) You know how everything in our universe is made up of atoms. These are our fundamental building blocks. And on the outside of all atoms, we have these electrons that spin around them, kind of like planets spin around the sun. When we get these electrons to leave the orbit of one atom, and jump over to the orbit of another atom, we have the movement of electricity. And because there are strong attractions and repulsions involved here, we have a form of “atomic power” that we can put to work for us.



Copper Atom

Definitions: Next, let’s be real clear about the words we use to talk about electricity. I find that technicians often get confused about electricity. And they often start by using words in a sloppy manner. And confusion leads to frustration, and then you get to the point of one tech I knew who used to yell at the top of his voice, “Mommy, mommy, I don’t want to be a mechanic!” (Yes, he was weird.) Frustration can do this to us, so let’s be clear. There are several words we use to describe aspects of electricity. Let’s go through them.

Voltage: Or just **volts.** This is the push that gets one electron to move from one atom to another. It’s the force behind electricity. And it’s the most common thing we measure. But it is only the push power. You can be fancy and call it: “electromotive force”. It is often symbolized by just the “V”, or maybe the “E “ for some of the formulas we use in electricity.

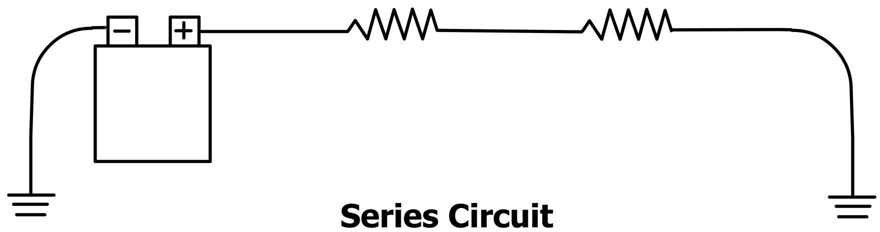
Amperage: Or just **amps,** is totally different. This is the number of electrons in motion. Sometimes we call it “current”. Imagine you are looking at a river, and you see all the water running by. If the current flowing by is very large, you know there is a large amount of water going past you. We often use the terms current and amps interchangeably. Or we might even call it “flow”. This might be seen as an “A” in a formula, or it might be an “I”, that stands for intensity. Just remember that the push of electricity and how much is flowing are two different things. I have so often seen techs get unclear about this, and then their thoughts on diagnosis don’t work. They get confused and frustrated.

Resistance: This is the resistance to current flow. This opposition is what keeps too much current from flowing. Example: if you were to be foolish and touch both terminals of a battery with a wire coat hanger, you would get too much current flowing, wouldn't you? (You'd probably get a fire and burn your hands, too.) Don't' do this. But it gives you the idea of why we need some resistance in a circuit. All circuits have a certain amount of proper, built-in resistance. We measure this as "ohms". So we might see the symbol "Ω" used, or we might see the "R" in formulas. We often use the word "load" in place of the word resistance. The load is whatever is in the circuit to do the work, like the light bulb or the wiper motor. But having too much resistance in a circuit is a common problem.

Watts: This is how much electrical power we have. And it takes both voltage and amps together to get this power. The formula is A x V = W. (W is the watts symbol.) You can figure it out by multiplying the amps and volts together. Just remember that it takes both together to have the power to get the electrical work done. So, when you are looking at a waveform of the voltage in a circuit, you know you are only looking at half the picture needed to totally understand what is going on. Fortunately, we now have some great new tools for looking at the amperage in a circuit.

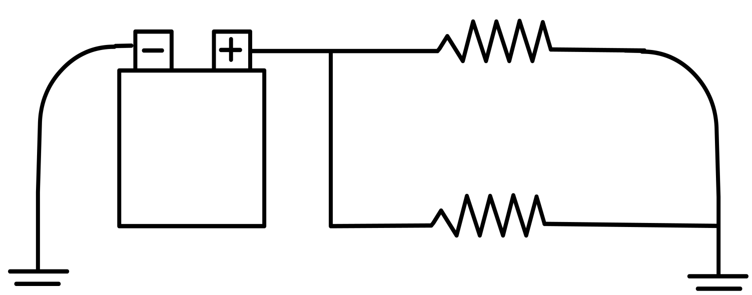
Types of Circuits: We need to know a little about circuit types so we know how to connect to our circuit with the different types of test equipment.

Series Circuit: This is where the electricity has only one path to follow, and all the electrons go through this one path. The power source, resistance or load, and wires all happen one right after another, in series. If we have to make a series connection to a circuit with a meter, we have to disconnect something, connect the wires of our meter in that place and make the electricity flow through the meter in series with everything else. We do this when measuring amps with a multimeter, but we don't connect our lab scopes up this way. We will measure amps with "inductive pickups" that clamp around the wire and sense the magnetic field of the flowing electricity.



Series Circuit

Parallel Circuit: This is where the electricity has more than one path to follow. There are different branches. Some electricity goes through "door number 1", some goes through "door number 2". When we measure voltage in a circuit with our lab scopes, we are creating another parallel circuit by hooking up our test leads.



Parallel Circuit

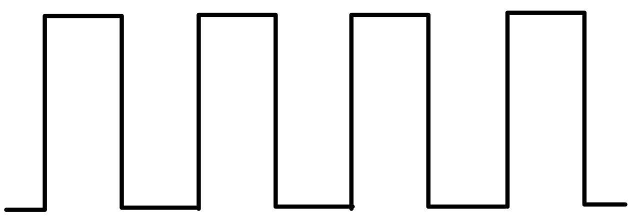
Because the internal resistance (actually impedance) of our lab scopes is so high, this is a safe thing to do. And it's also very easy; we don't have to disconnect anything.

Digital Signals: There are several types of digital signals we need to understand, so we can tell what is good, and what is bad. It also helps us understand what the computer needs to see.

Frequency or Hertz (Hz)

How many of these we have in one second is the cycles per second or Hertz

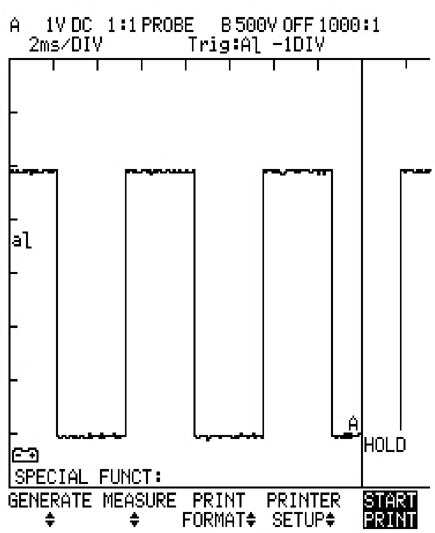
159 Hz would be 159 cycles of up and down in one second.



Hertz, or Hz: Hertz means cycles per second. It's also called the frequency. Hertz signals cycle on and off. We see the voltage toggle up and down. And they do it at a regular rate. What matters here is how fast they do it. This is what the computer is looking for. But they spend half their time being high voltage, and half their time being low voltage. For example, a mass air flow sensor might cycle at about 2000 Hz at idle, but increase to over 6000 Hz when under heavy power. Or a Ford MAP sensor might show 159 Hz with normal air pressure in the intake manifold, but under idle vacuum show 109 Hz. The computer is just counting how often the voltage goes up and down.

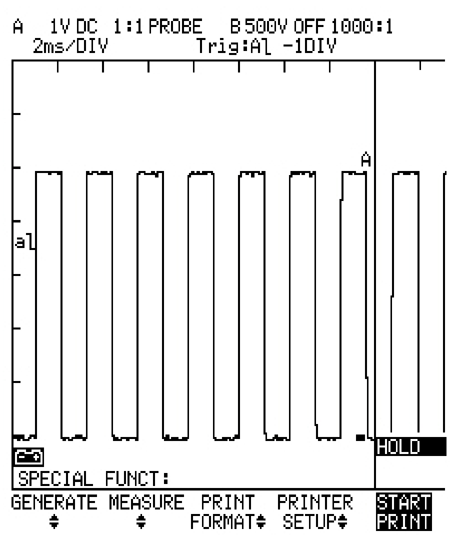
Difference in Hertz, or Frequency:

The time per division is the same in both screens.



This pattern cycles up and down very slowly, it has a lower Hz or frequency.

This pattern cycles up and down more quickly, it has a higher Hz or frequency.

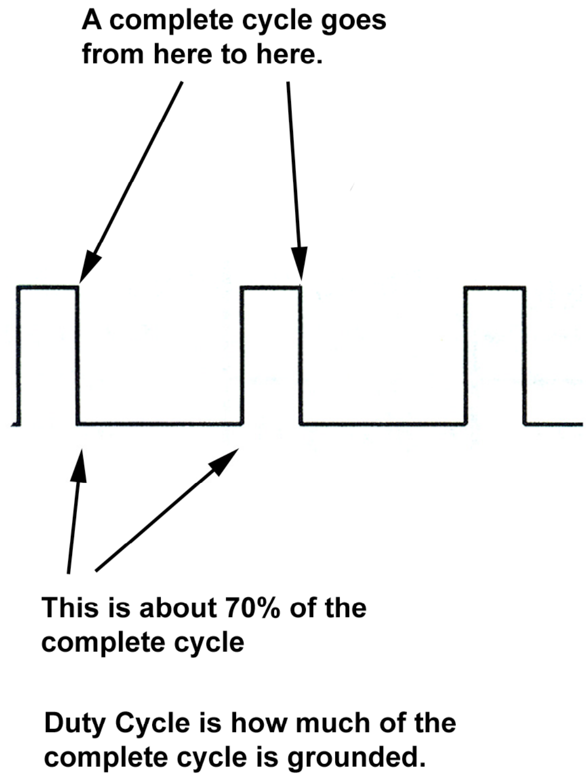


Both these patterns have a 50% duty cycle. They spend half the time at high voltage, half the time at low voltage.

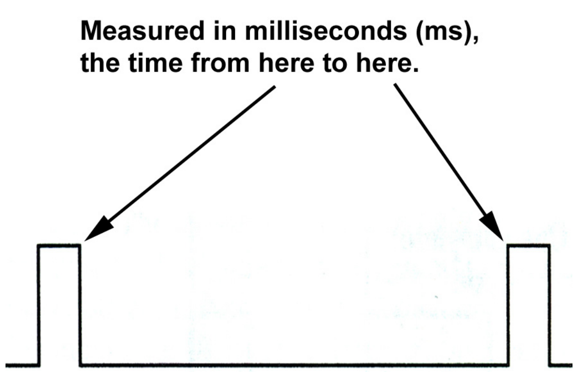
Duty Cycle (or %): This is different than frequency. This measures how much of a complete cycle was low voltage time. Since grounding them usually turns on solenoids, the “on-time” is low voltage time. If we look at the percentage of low voltage time, we can know how much the solenoid was turned on. We might have a solenoid that is grounded more or less to control how much vacuum we get to an EGR valve. Or how much purging we get in an EVAP system. Or how much we lean out a feedback carburetor.

Some of you might remember when we measured GM feedback carburetors with a dwell meter. A high dwell meant the carburetor was leaned out a lot. And we only had from 0 to 60º of dwell to play with. With duty cycle, it’s about the same thing, except we use a %, so we have from 0 to 100% to show how much. 100 % would mean it was grounded all the time, 20% would mean it was grounded only one fifth of the time.

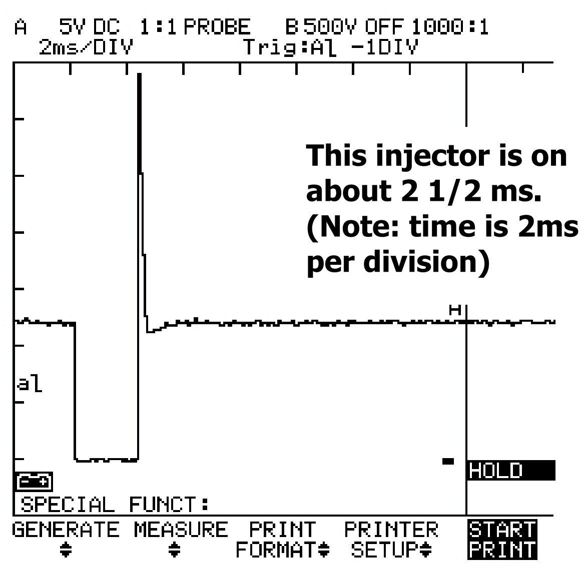
70% Duty Cycle:



Pulse Width (ms)

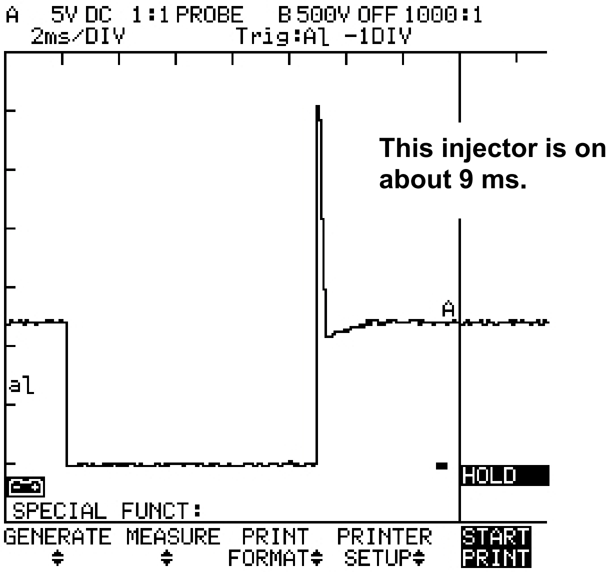


Pulse Width: is a measurement of time in milliseconds. (Thousandth of a second) It also usually measures “on-time” that is low voltage, or grounded time. We measure fuel injectors with pulse width.



Number Symbols: When we look at a scope screen, there are symbols there we need to understand. Often they go with some numbers to tell us the time or voltage we are looking at. I tell my students: “Suppose I gave you 10 in your checkbook?” They look at me with blank faces, because they don’t know how much I gave them. If I gave them 10 cents ($ 0.10), who cares? It’s not enough to matter. If I gave them 10 dollars ($ 10.00), now we are talking something

useful. At least they might get lunch. If I gave them 10 thousand dollars ($10,000.00), this would be something. And if they got lucky, and won the Lotto and got ten million ($10,000,000.00), now we're talking. Now they can take me out to lunch.



See how with the big numbers we had to use a lot of zeros to show it? But on a lab scope or multimeter, we don't have enough space or numbers for that. We use symbols and move the decimal place around, to express our very large and small numbers. And we will need to express time as low as one thousandths or even one millionth of a second. Sometimes we need to express volts as high as many thousands. So you need to know how to express these numbers with symbols.

Milli or m: (notice the small m) means one thousandth. So one thousand millivolts (mv) equals one volt. Or one thousand milliseconds equals one second. We use this symbol a lot. You might see a lab scope time setting of 5 ms/div. If something lasted two divisions, that would be 10 milliseconds. That would be 10 thousandths of a second, or 1/100 of a second.

Kilo or K: means one thousand. We usually use this one for voltage. 14 Kv would mean 14,000 volts.

1 milli (m) = 1/1000th of anything.

235 mv = 0.235 volts 1000 mv = 1 volt

1000 msec = 1 second

1 Kilo (K) = 1000

14 Kv = 14,000 volts

Micro or µ: This equals one millionth. It would take one million µs to equal one second of time. So 10 µs/division would have 10 millionth of a second per division. 500µs/division would be half a ms per division.

Mega or M: (notice the big M) means one million.

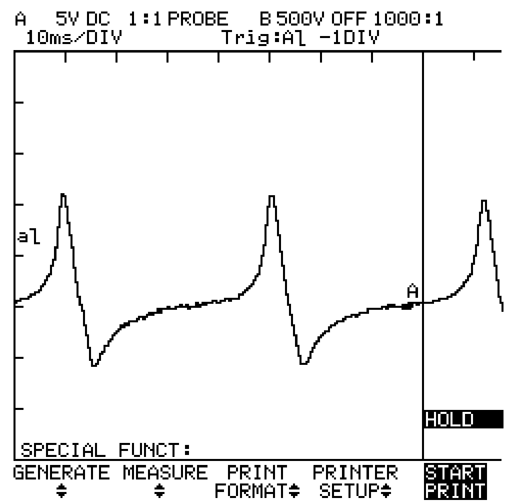
Chapter 3

Pattern Recognition

You're probably anxious to get out there and hook up your scope to get some patterns. Can you be patient for one more chapter? I think we should go through some basic patterns first. You will get familiar with some of the basic waveforms you need to see. And it will show you common voltage and time settings. It will help you recognize what is good and what is bad. But I'm only going to show you good patterns here.

Magnetic Pickup RPM Sensor

Here's a basic magnetic pickup pattern; also called a permanent magnet generator, or P.M. generator. Notice how the pattern goes above and below the zero point.

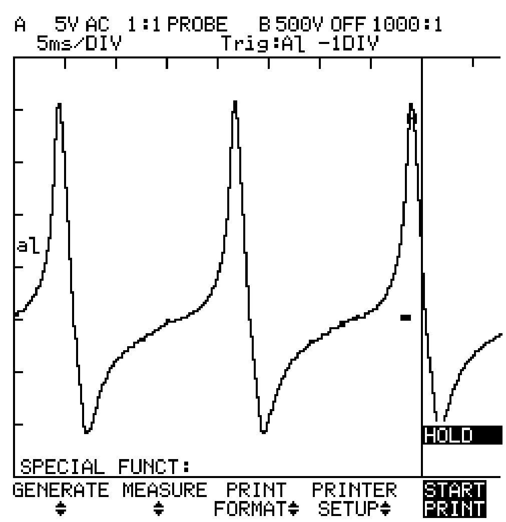


Magnetic RPM Sensor at Idle

At low rpm, the voltage peaks don't get very high, and the pattern doesn't repeat very quickly.
5v/div, 10ms/div.

This will get taller at higher rpm, and shorter at lower rpm. And it will go faster at higher rpm, (you would see more up and downs in the same screen.) And you would see less at lower rpm. If the voltage didn't get high enough, the computer wouldn't recognize it. The Computer just counts the downward drops.

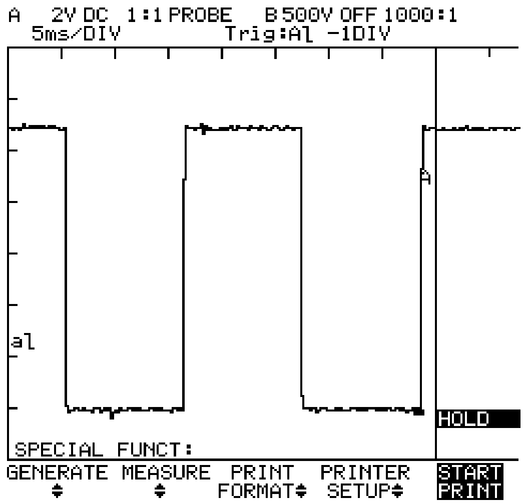
This next pattern is at 1500 rpm. You see how the voltage peaks get higher, and the pattern happens faster. This pattern is at 5ms/div, not 10ms/div, so the changes are happening more quickly, even though the two patterns look almost the same.



Magnetic RPM Sensor at 1500 RPM

At higher rpm, the voltage goes higher and lower, and the changes occur faster. Notice, this is at 5ms/div, not 10ms/div.
5 volts/div., 5 ms/div.

Hall Effect RPM Sensor



Here's a Hall Effect RPM sensor. The height of these can be different on different manufacturer's cars. This is a Ford; it goes up to about 11v and down to zero. GM or Chrysler may only be 0 to 5 volts.

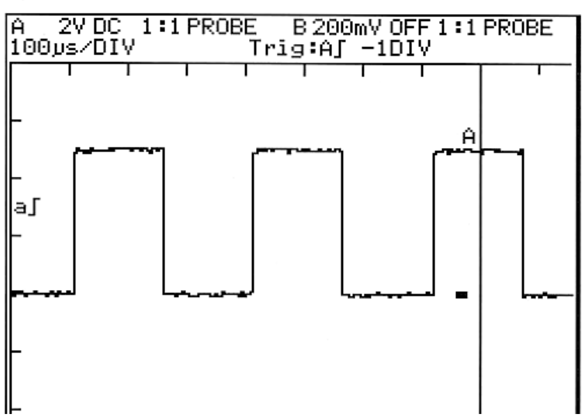
Hall Effect RPM Sensor

Square wave goes up and down from 0 to 11 volts on Ford. GM and Chrysler may be 0 to 5 volts.
2 volts/div., 5 ms/div.

The height of these square waves will not change with rpm. But the pattern will get faster or slow with changes in rpm.

These are a DC voltage that doesn't go below the zero point. And the pattern is 50% at high voltage, and 50% at low voltage for most manufacturers. (This is called the duty cycle.) Chrysler does have a changing pattern in the duty cycle to help the computer recognize where the engine is in the firing order.

Optical RPM Sensor



Optical RPM sensor

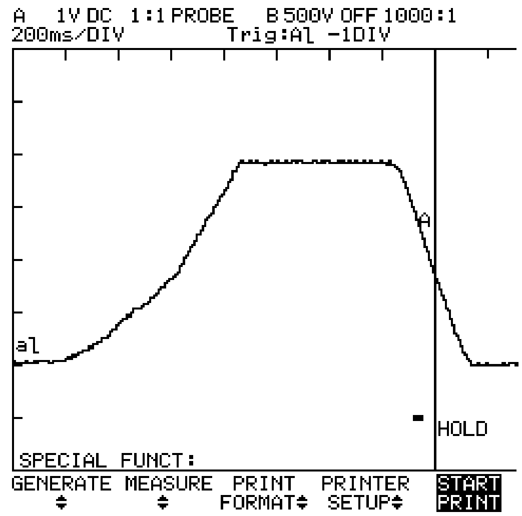
Look at how fast this is, at 100μs/div. These can have a pattern that tells the engine computer the position of the engine.
2v/div, 100(s/div.

Here's an optical RPM sensor. You may say it looks about the same as the Hall Effect, but look at the time per division. That is 100 millionth of a second per division, or one tenth of a millisecond. These sensors can be very fast. And they can have a pattern in them too. Some may be longer or shorter to tell the engine computer which cylinder is on top. These are a DC voltage, usually going up and down with 5 volts, just like this one.

This about covers it for RPM sensors. They are going to be one of these three types. But the patterns may look different for different types of vehicles.

Throttle Position Sensor

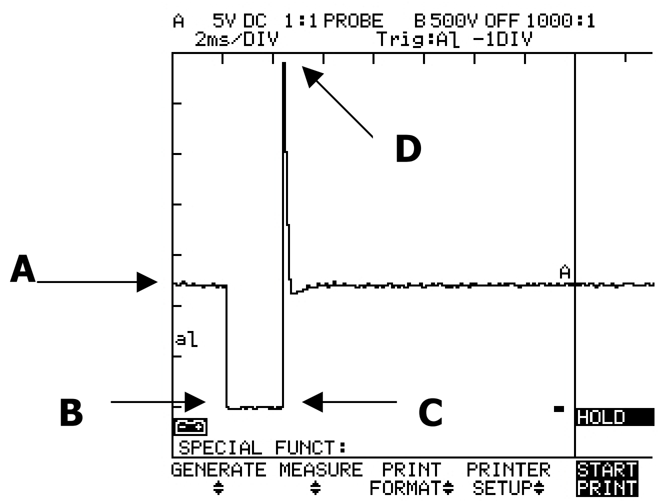
Here's an example of a Throttle Position Sensor sweep. You see us open and close the throttle, and the voltage goes up and down. If there was a really bad spot on the potentiometer contact strip, you would see the trace go down suddenly where it shouldn't. This causes all sorts of havoc in how the engine runs—everything from hesitation, stalling or even an intermittent fast idle.



But I must tell you here, testing a TPS with a lab scope is not the best way to catch intermittent TPS. Do a ohms sweep with a digital DVOM and watch the analog bar graph. That is really sensitive, and problems will show up there that won't show up anywhere else.

Fuel Injector

Let's look at the different parts of the fuel injector pattern. This is just a basic port or sequential injector where battery voltage goes to the injector coil, and the computer grounds the coil to create the magnetism to open the injector.



A shows that beginning voltage level. This is usually close to system voltage.

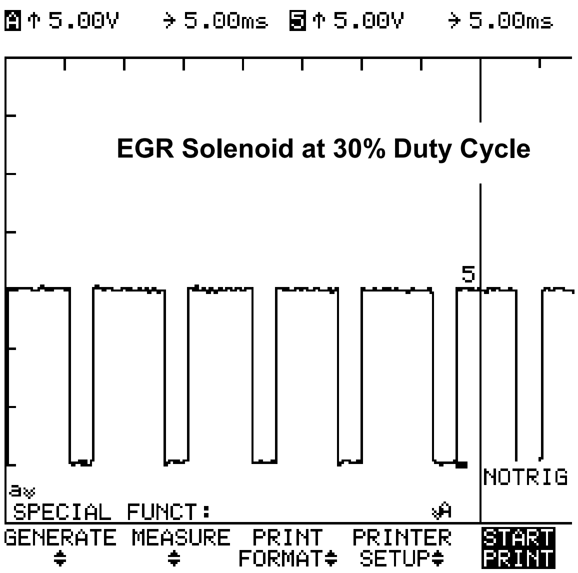
B shows the voltage dropping low as the computer grounds the coil. If this doesn't get close to zero, there could be ground problems, or a weak computer transistor can't pull the voltage low.

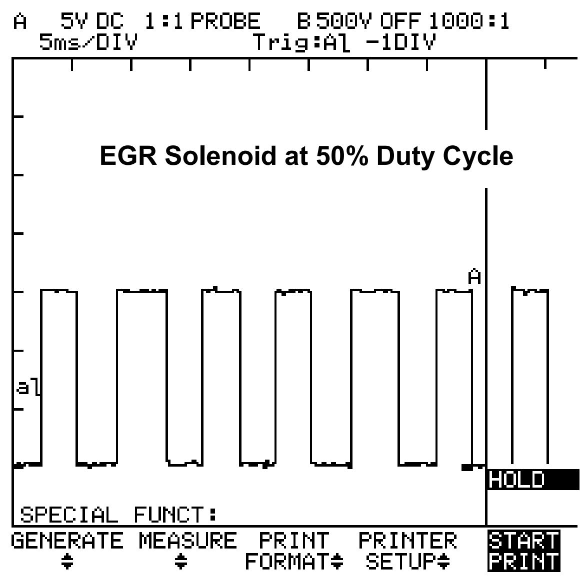
C shows the computer turning off the injector by no longer grounding it. The voltage goes up. From **B** to **C** is the "on-time" of the injector.

D When the coil is turned off, the magnetic field collapses, and this generates a spike, similar to an ignition coil generating a spark. If this coil doesn't go up very high, it shows the magnetic field wasn't very strong. Could be shorted coil windings in the injector, or low amperage to the injector for some reason.

Duty Cycle

This is an EGR valve vacuum regulator solenoid being turned on with a duty cycle signal. Battery voltage is being grounded about 30% of the time, at a fast cycling rate. This gives a small vacuum signal to the EGR valve to turn on the EGR valve a small amount. When we want more EGR, the EGR is grounded at a higher duty cycle, like 50%, and this gives more vacuum to turn on the EGR valve more.



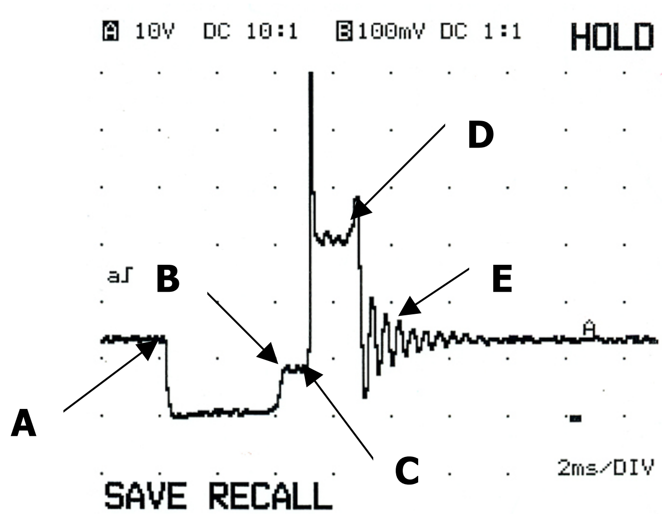


Ignition Primary

The function of and ignition coil is in some ways similar to the fuel injection coil. We ground the coil to create a magnetic field, and then unground the coil to get the field to collapse. It's this moving magnetism, as the field collapses that generates a spark in the secondary coil windings.

A is the voltage before the primary side of the coil is grounded. This should be close to system voltage. It is also the start of the time when the coil is grounded by the ignition module or computer.

B is when there is current limiting applied to the grounding circuit. It keeps too much current from running through the coil, so it doesn't overheat.

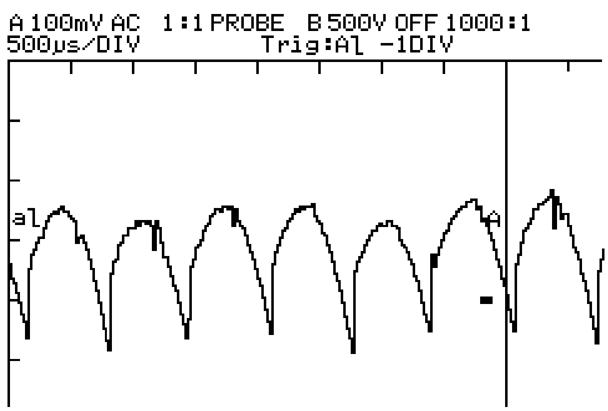


C is where the coil is ungrounded. **A** to **C** is the dwell time, or saturation time to build up a big enough magnetic field so that when we let it collapse, it will generate a strong spark for the plug. If we don't have a long enough dwell time, there won't be a strong enough spark.

C to **D** is the time when the spark is flowing across the spark plug. This is usually 1-2 ms. If this is too short, or too long, we get suspicious. We would look for something that has caused to much or too little resistance in the circuit of the spark plug.

E are the coil oscillations, as the spark runs out, and the electrical surges dissipate. It used to be a strong system showed good oscillations. But many modern systems don't show strong coil oscillations, because the dwell time is some closely controlled.

Alternator Ripple



Alternator diodes and stator windings are even here, as show by the even humps on this pattern.
Good Alternator Ripple, don't worry about the little bit of noise.
100mv AC/div, 500μs/div.

These even humps show the alternator diodes and stator windings are working properly. This has to be checked with an AC coupling. And the system has to be charging to see this, so I raise the engine rpm and either turn on the headlamps, or load down the voltage with a carbon pile. The short up and down lines in the pattern show a little bit of electrical noise. Don't worry about it. Memorize these settings. They are important to see this.

Chapter 4

Getting a Pattern on the Scope

O.K. you've been waiting long enough. Now it's time to turn on your scope. The button may be green, it may say "on/off", or "power". It might have that universal symbol of the "1" for on, and "0" for off. Or it might be totally different. But go ahead and turn it on.

What if nothing happens when you turn it "on"? Don't feel stupid, this actually happens a lot. (I assume you have the right "on/off" button. One time it took me all day to find the right button on a new computer.) Two common possibilities**:**
1: The batteries are dead. This is when you haven't used the scope for a while, or maybe you just got it. Batteries often have to be charged for 8 to 24 hours before they work right. But most scopes should run during this time. But don't be surprised if you have to charge a really dead battery for a couple of minutes before it will turn on. Just be patient.
2: The screen contrast is set wrong. There is a setting to adjust the screen darker or lighter so it will look better in different lighting conditions. Sometimes you may think your machine is totally dead and broken, but it's just that the contrast is set where you can't see anything. This can be a problem, though, if you don't know how to adjust it. You can't see anything on the screen to guide you. So you might have to get with somebody who has one like it, or call the manufacturer to have them guide you through which buttons to touch.

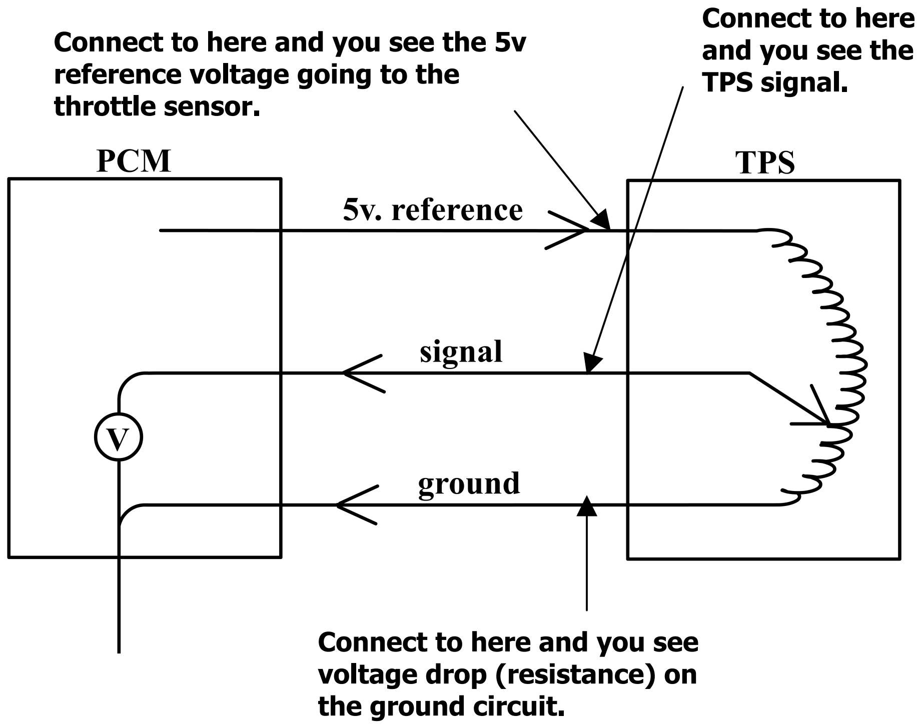
Where to connect the test leads?

You usually have a black test lead and a red test lead to connect to read your signal. (Some scopes get creative with blue, green, gray or yellow test leads too. It doesn't matter.) You need both of them connected. One is positive, (usually red, or some alternative color), the other is black. This is your negative, or ground test lead.

The Black Test Lead:
I usually connect my black test lead to a good ground somewhere on the engine or chassis. It's best to be somewhat close to your signal. The perfectionist is going to say I should use the ground wire at the sensor to get the best reading. Fine, he can do that, but I usually want to look at a number of signals in a short time, so I save time if I can leave my ground lead attached to one place. This will work for most signals. I can check for voltage drop on the ground wire later. Yes, you can go to the battery ground too. But there is often a lot of electrical noise there. Kind of like Grand Central Station, with everybody shouting at one time. It's not the best.

The Red Test Lead:
This is the lead we connect to the signal wire. Whatever you want to measure. You just have to find the wire.

Warning! I should warn you here that there may be one or two ways you could hurt yourself, though, if you are not careful. Most circuits you want to look at are battery voltage or less. No problem. For years we have been able to roam around the electrical system and touch anything with our bare hands, except secondary ignition, and there was no problem And even secondary ignition didn't hurt that much before electronic ignition.

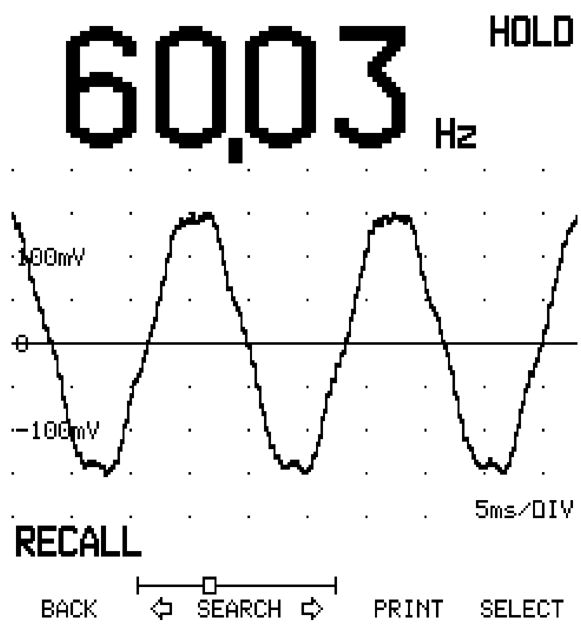


But things are different under the hood now. Computer controlled diesel engines and hybrid electric vehicles have changed all that. Be very careful if you are connecting to high voltage. (I consider high voltage anything over 50 volts) Make sure you are well insulated. Don't use your bare hands. Use insulated gloves. Computerized diesel engines, like Fords common rail system can be dangerous because there is over 100 volts to turn on the injectors. And there is high amps available there too. This could kill you. The electrical hybrid Honda Insight has over 100 volts in places. And the Toyota Prius runs close to 300 volts. (Or even 500 volts with the new one.) You don't want to mess with these and discover the answer to the old question of whether or not there is life after death. Be careful. And don't tap directly into secondary ignition, (like spark plug wires) ever. I shudder when I think of the guys who tap into the plug wires with a test light to do a cylinder balance test. And then someone comes along later, and leans on the distributor cap and gets shocked. Even primary ignition can get up from 200 to maybe 600 volts, in the right conditions. I have heard Chrysler primary ignition can hurt you.

To look at a computer input, like an O2 sensor, or TPS, you can just find the wire at the sensor harness. Don't get too worried that there are three or four wires there, and you

don't know which one. There are lots of ways to do this. You can check various sources for a connector or wiring diagram. This might be the factory wiring diagram, or it might be an aftermarket source like Mitchell-on-Demand, or Sumdata, er I mean Alldata. (No offense, I do like a lot of what they do.) Or you might find the diagram on your Snap-on Vantage scope, or your OTC Perception. (Yes, these are some that have the diagrams right inside them. They're just a bit expensive to update every year.) But you can also just go probing the wires and figure out what you have. Because you are making a parallel connection with very high resistance, you are not going to hurt the circuit if you connect to each one until you find the one that looks right. In the example of the TPS above, you might find 5 volts on one wire. (That's probably the reference.) You might connect to another wire, and you get 0 volts. (That's probably the ground. If you weren't connected to anything, you would see the random waviness that shows you aren't connected to anything. And then you could connect to the last wire and probably see your voltage go up and down as you open the throttle. If you were to get 0 volts again, you'd have to see which is the signal wire and which is the ground. You could use your diagrams to narrow this down.

When you are using a wiring diagram, remember the colors will work for the side of the harness that goes to the computer. But the side close to the sensor may have different colors than the wiring diagram. Harness diagrams are good, just remember which direction to look at the real harness. Usually the wires will be coming out the back, away from you when you are looking at the right side.



This wavy pattern shows the scope is not connected to a wire, it just acts like an antenna. This will be smaller when the voltage per division is larger.

Notice how the cycle of the pattern was from a source that cycled at 60 Hz, like our power grid.

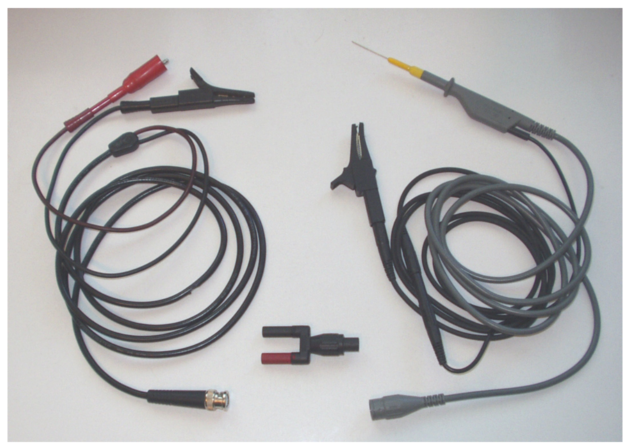
A note about what the pattern looks like **when you aren't connected to anything**. Yes you can really tell because your scope test leads tend to act as an antenna and pick up all the stray radio noise around us. There is lots of it. And it usually makes the pattern have an AC sine wave pattern to it. Even with shielded wire test leads, designed to minimize this you will still see some of it. The size of this waviness will be smaller when your voltage settings are higher, and larger when your voltage settings are smaller. But

when you are connected to a wire on the car, this grounds out the antenna signals, giving them someplace to go, and the AC waviness goes away. This is important, because the most common problem I see with technicians using their lab scope is they don't make a connection with the wire they want to measure.

About shielded wires and electrical noise. Shielded test leads for your scope are like the wires for your VCR or TV cable. They have a protective wire wound around the outside of the regular wire. Then they put insulation on the outside of the whole thing. This protects the wire from picking up electrical noise. If you don't have shielded wires for test leads, they can act like an antenna. Even when you are connected properly to a signal wire, if you are near some high voltage signal like ignition wires or fuel injector wires, you can pick up the electrical noise. Having shielded test lead wires can protect you from getting some really weird patterns. One time I was checking the oxygen sensor signal on a motor home, and my unshielded test leads were near the distributor. So I picked up the ignition pattern on the oxygen sensor line. What a confusing pattern. For a while, I thought there was something really weird going on with the vehicle.

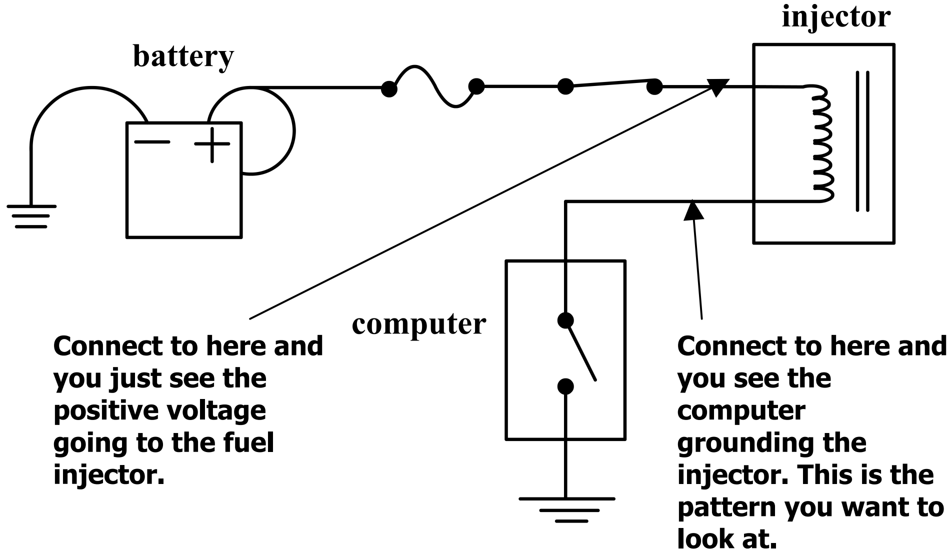
Shielded test leads protect your signal from extra noise. Without them, you have to be very careful what you lay your test leads next to.

BNC to Banana Plug adapters are used to connect to some lab scopes

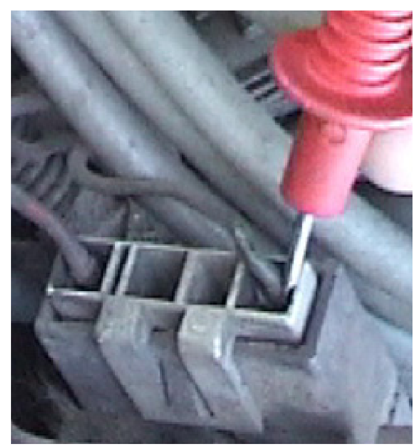


To look at a computer output, like a fuel injector or EGR valve, you must connect to the wire that has the voltage switching up and down on it. If the injector is controlled by the computer grounding the negative or ground side of the injector coil, you won't see this working by looking at the positive voltage going into the coil. That would only check that there is voltage going into the coil. The negative side of the coil will be high voltage when the computer has not grounded it, and low voltage when it's grounded. This is what you want to see.

The same would be for an EGR valve that is grounded by the computer to turn it on, or an EGR solenoid that sends vacuum to the valve when it's grounded by the computer. These are all just solenoids. (Coils of wire to create magnetism to move something.)



How to connect to the wire: Sometimes you just clamp on to the wire when it's out in the open like an alternator output stud, or a battery terminal. But often you have to get inside a connector or some weather protection seals. You are either going to pack-probe into the wire, or pierce the insulation to get to the wire. (Some don't agree with piercing the wire, we'll discuss this later.) Some vehicles have systems for attaching a break-out box. If it's easy to get to, fine. But some are not, and I don't bother.



Sometimes it's easy to connect to the circuit you want to measure. But often you have to do more to connect to a wire.

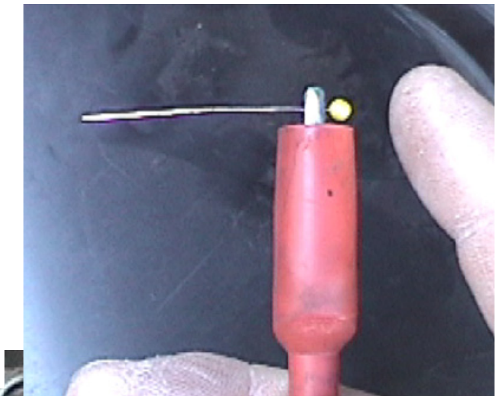
How To Back Probe a Wire

Often we can't see the terminal we want to connect to at all. But we can connect without having to puncture the wire. The idea with back probing a wire is we're going to sneak down between the wire and the insulation of the connector that keeps the moisture out. If we get down far enough, we can connect with the metal terminal on the inside. And the rubber weatherproof insulation will help hold our pin in place.

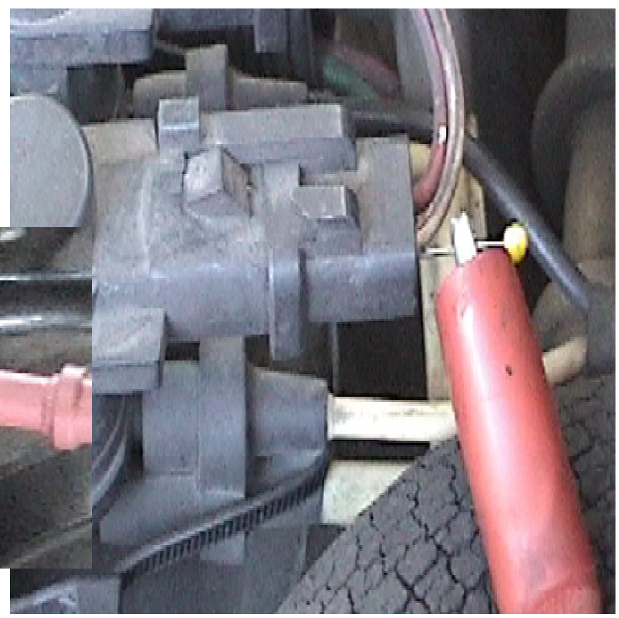
Make sure you probe down far enough. Often students don't go far enough. And watch that you don't pull out and loose your connection.

These are some tools good for probing down between the wire and the insulation of the connector.

Don't puncture the wire, just insert until you contact the metal terminal on the inside.

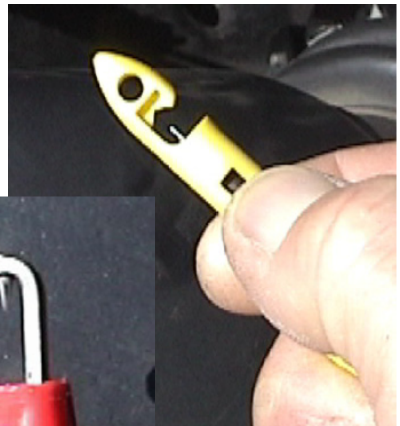


This shows how far down the wire you often have to probe to make contact with the metal terminal on the inside.



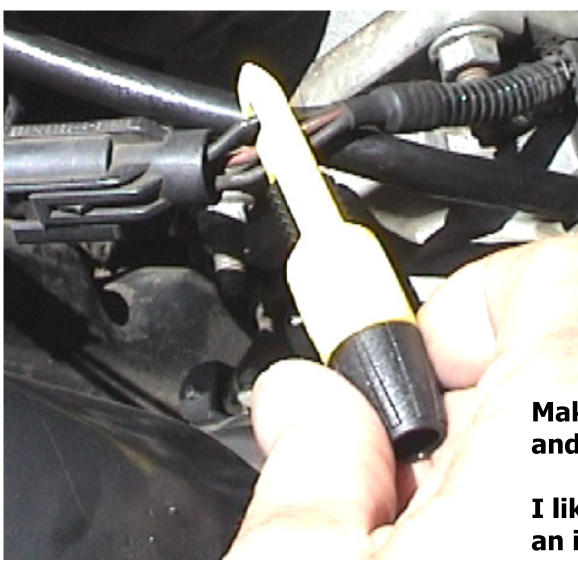
To puncture or not to puncture the wire:

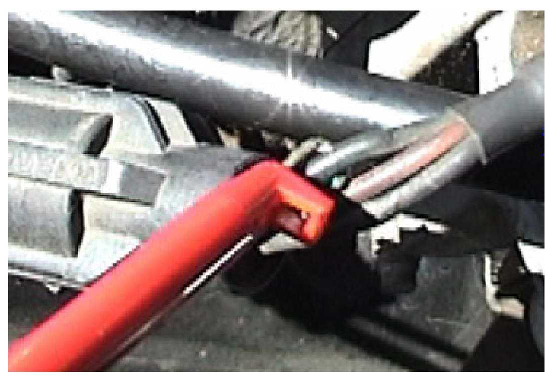
Why not? Some will argue you should never puncture a wire. It will cause problems. You could break one or more of the strands on the inside. You can let in moisture (and salt in some places where they salt the roads for snow) and cause corrosion in the future. Or you can end up tearing the outer covering so you really destroy the wire. These are all true. And if you are not going to be careful and responsible, I agree, you shouldn't puncture the wire.



Here are some tools used to puncture a wire and keep a good grip on it.

Why do it? I puncture the wires because it's easy and I know I am getting a secure connection. I deal with a lot of intermittent problems and I want to know that if I see a glitch on my scope, it was the circuit acting up, not me getting a poor connection. But I am very careful not to destroy the wire. I admit, I did damage a few when I first started doing this and hadn't gotten a feel for it. With practice, you can be quite gentle on the wire and only leave a small prick that almost fixes itself. Some tools do leave a bend in the wire, but I don't consider that a problem. Electricity does go around corners. (Did you know when they first thought about lighting streets with electricity, they were concerned that they couldn't bend the wires and have it work. I would only worry about this when protecting for lightning, like in a sailboat, because it's such a strong jolt. Electrons do have a little mass.)





Make sure the pin is centered on the wire, be gentle, and you can connect without tearing up the wire.

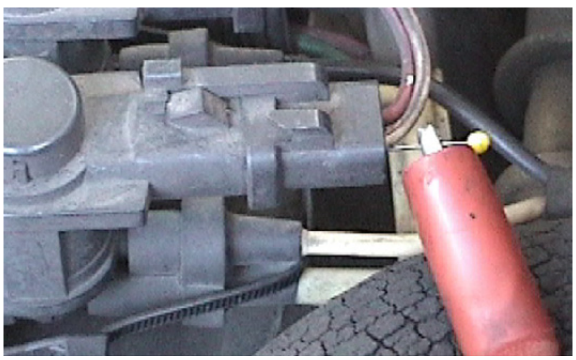
I like this connection because it's secure. If you have an intermittent you want to make sure the glitch you see is not a poor connection you have with the wire.

You can seal up the hole afterwards with fingernail polish or touch-up paint. If you did it right, it will only be a very small prick.

Back to puncturing wires. Be sure you seal up the hole. Don't use silicone sealant because it releases an acid when curing, and that's not best on the wire. Maybe you don't have fingernail polish (or are afraid to be caught with it), but you probably have some touch-up paint around. That will do.

How to Puncture the Wire

Remember you have to line up the sharp pin on the inside with the center of the wire. It's really easy to get off-center, and then the pin won't get to copper strands in the middle. Then you give a gentle tug, or tighten the knob, to set the pin in the middle. And pay attention to the pressure from the wire lead on the tool. It can pull on the wire you're puncturing and unseat it or pull it off center. Another thing to watch: don't lay the leads over some high voltage source, like the ignition coil or plug wires. Then, when you are done, seal the wires like we talked about above. Just in case you ever had the bright idea of using electrical tape to seal them, forget it. The glue doesn't hold worth beans. I use silver duct tape when I have to tape up some wires. It's not as pretty, but I'm not going to kiss it. I just want it to hold really well, and the duct tape does that.



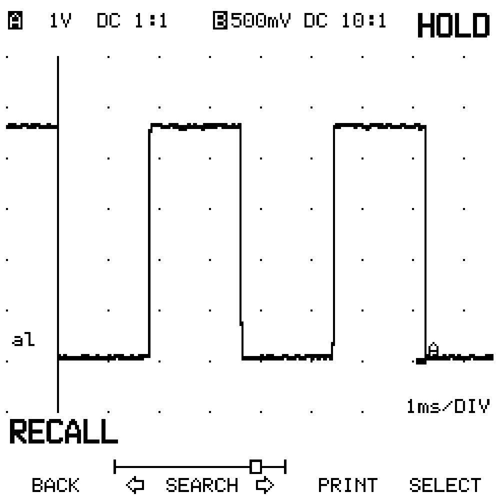
The pin has to go deep enough to touch the metal terminal on the inside, or you don't get a connection.

This fancy tool will back probe, and not have much bare metal that could accidentally touch something and short out the circuit.

What to Adjust? Or Why Doesn't My Pattern Look Right?

OK, so you got the wires hooked up to the circuit, and you've got something on the scope, but it doesn't look right. What to do now? You probably have to adjust the settings on the scope so you can see the detail you need on the pattern. This is partly why you need to know what it should look like. So you can adjust to see the right stuff. That's why we spent time in chapter 3.

Let's look at what happens if the voltage, time or ground position are not right. A picture is worth a thousand words. Here's a good pattern, to give you an idea of what we are trying to look at.



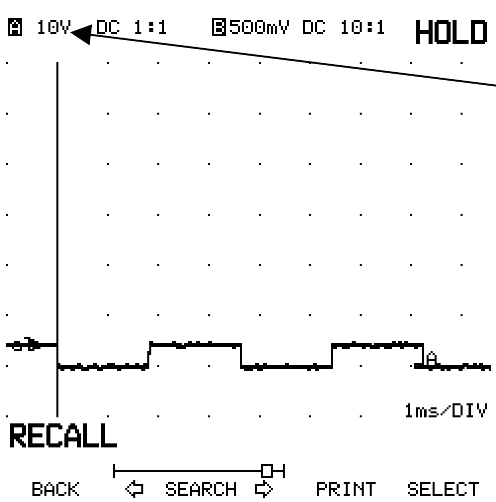
A normal pattern, with good adjustment of time, voltage and ground position.

Good adjustment allows us to see a lot of detail. The pattern fills up a good portion of the screen.

This square wave goes to almost 5 volts, and does a complete cycle in almost 4 ms.

Voltage Adjustment

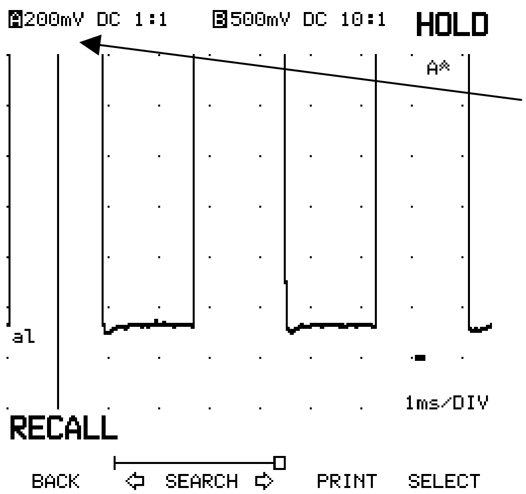
Here's what can happen if your voltage adjustment is too large. It makes the picture look too small.



This voltage setting is too big. So our pattern that only goes up to about 5 volts looses detail.

There may be things going on in this pattern we can't see.

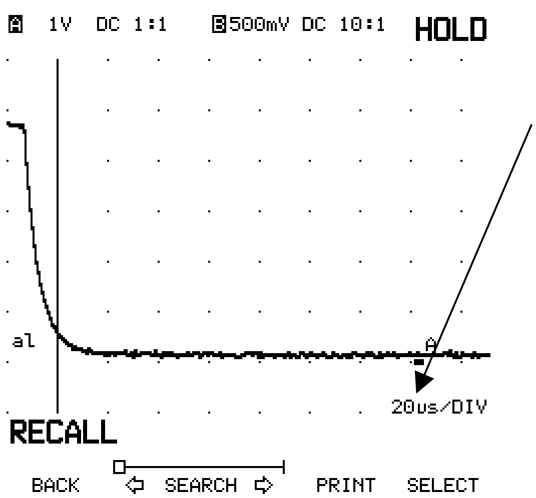
The next trace shows what can happen if the voltage adjustment is too small. The picture gets too big, and you only see part of it on the screen.



With the voltage setting too small, you can’t see all the pattern.

Time Settings

A lot of students end up with a time setting that is too small. So you only see a small part of the pattern, but it’s really magnified. You can see lots of weird stuff that’s really normal.

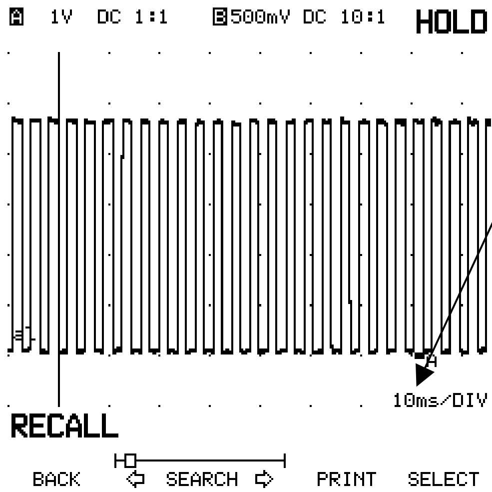


This is a real small time setting.

If the time settings are too small, you only see a small section of the pattern.

And because it magnifies a small part of the pattern to look real big, you see funny shapes and might think something is wrong, when it’s OK.

If the time settings are too large, you get the pattern squished together and can’t see what’s going on. And the scope update rate may slow down, so it is sampling at a slower rate. Very inaccurate things can happen. You may think you’ve found the problem, but really it’s just a setting on your scope.

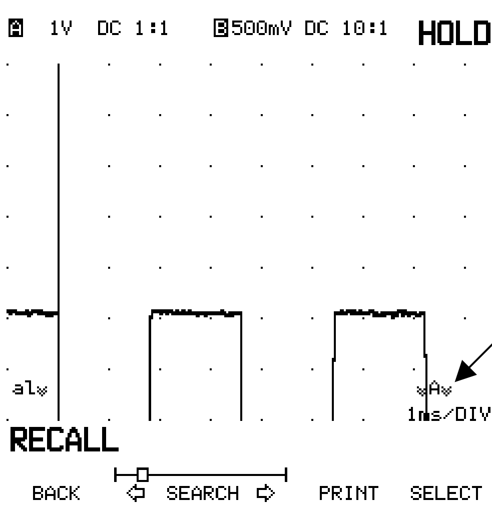


With this time setting so large, you loose a lot of detail.

On some scopes, with the time set too big, the update rate slows down, and you see a weird pattern from aliasing—The scope can't draw enough dots to make the picture look right.

Ground Positioning

If the position of zero, or your ground gets off, then the whole pattern can move up or down. Then you can't see it all.



This weird pattern is caused by putting the ground or zero point too low, and off the screen.

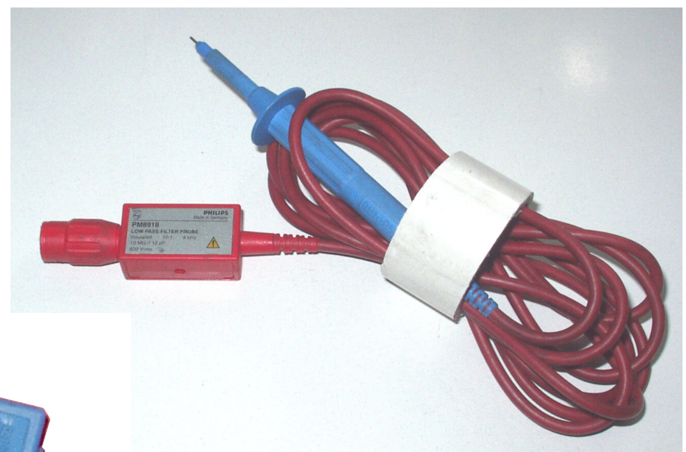
This "A" shows the ground or zero symbol is off the screen. This can easily happen if you push the wrong button and aren't paying attention.

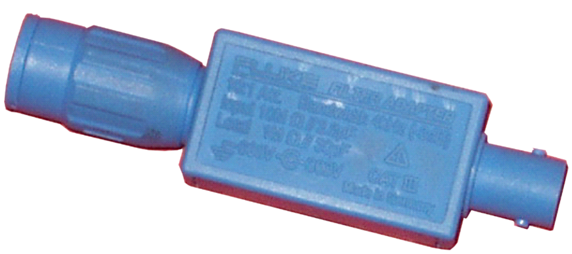
10:1 Probes

10:1 probes will take 10 volts at the signal wire and turn it into 1 volt going into your scope. They are used for several reasons. Many lab scopes are rated at 1 meg input impedance, but it would be better to have them be at 10 meg impedance. (Simply stated, the input impedance is the internal resistance of the scope. With higher internal resistance, you affect the signal less when you attach to it for a measurement.) By using a 10:1 probe, you do this. It also takes out some of the electrical noise. For these reasons, many like to use them when testing oxygen sensors. The 10:1 probe also allows you to read higher voltages than your scope normally reads. And if you don't have software to tell your scope that you are using a 10:1 probe, you have to do the calculations yourself. Know that when your scope shows 40 volts, it's really seeing 400 volts. In a later chapter, we will use 10:1 probes when measuring primary ignition. Many scopes can't measure primary ignition without it. When the voltage gets up to 200 volts, they ground the signal to protect the scope. With a 10:1 probe, the scope only sees 20 volts and doesn't freak out.

These **10:1 Probes** reduce voltage spikes to protect your scope

Only one tenth the voltage now gets to your scope, unless you set it for 10:1





If you are using a Pico scope attached to your laptop you will need a 20:1 probe, or attenuator, to protect the scope. It can't handle a very high voltage.

Sampling Rate

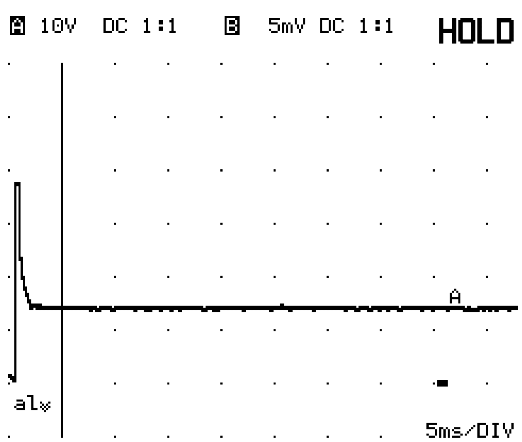
Sometime you can have problems if you don't understand how the sampling rate of your scope affects the pattern you get on the screen. Your scope is constantly collecting dots, and then making a pattern out of them to put on the screen. For the pattern to be accurate, you must collect the dots quickly enough to not loose anything. If you collect the dots slowly, things can happen you don't see. And your scope can draw a pattern based on incomplete information. But if your scope was to be so fast and accurate to capture every bit of stray electrical noise you could end up with a pattern that looks like a big blob because there is too much information there. The makers of your scope have tried to balance out this problem when they put your scope together. But sometimes you have to help them by adjusting things differently.

What to do: Experiment with making your time division larger or smaller to get a clear pattern. This affects the sampling rate on many scopes. So if you want more detail, select a smaller time division. Some signals are really fast, and you must adjust your time small enough to get them accurately, or they can give you a false pattern (called "aliasing"). When in doubt, adjust to a smaller time and make sure the pattern responds correctly. If you want more detail, you might select the "min/max" or "glitch capture" options. This puts some scopes in maximum capture speed, and you get the most information. But sometimes it's too much, and you have to turn it off. Know that the LS-2000 and ADL-7100 (good scopes by the way) are always in glitch capture mode. If you get too much noise, you might have to use a 10:1 probe or other filter to lower the noise.

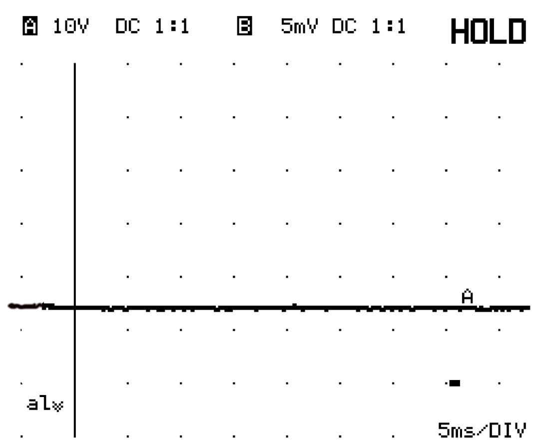
Chapter 5

Trigger

Trigger helps the scope know when to start drawing the pattern. For instance, voltage at a fuel injector goes on for a long time at battery voltage. Then the injector fires, and the voltage goes down and up with the changes you want to look at. But you don't care about the part that is only battery voltage. You want to watch the pattern as the injector fires. But how does the scope know what you want to look at? Trigger is how you tell it what you want to see.



Both patterns don't show the fuel injector pattern you want because the trigger isn't set right.



The trigger voltage is set too low. The pattern never gets to that low a voltage, so trigger isn't used to draw the pattern.

Trigger tells the scope when to start drawing the picture. Kind of like an alarm clock that tells you when to get up. Before the alarm goes off, you just lay there. Trigger is a voltage level that tells the scope: " When you see this voltage, start drawing the pattern." But it also needs to know whether to start drawing as the signal goes up to that voltage, or down to that voltage. That's called slope. **Positive Slope** is when it goes up to the voltage and **Negative Slope** is when it goes down to the voltage.

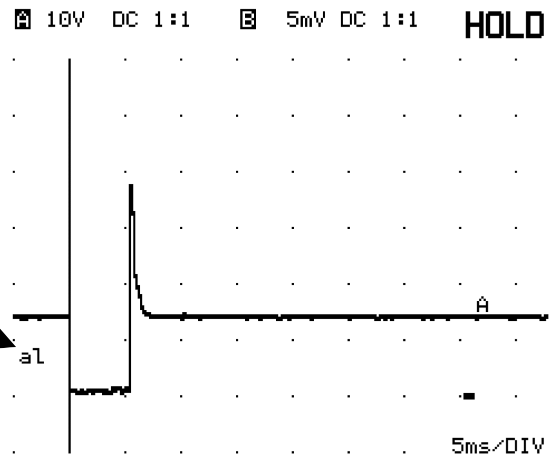
Negative Slope symbol – the pattern will start as the voltage goes down to the trigger voltage.

Positive Slope symbol – the pattern will start as the voltage goes up to the trigger voltage.

With the trigger set right, you see the injector pattern correctly.

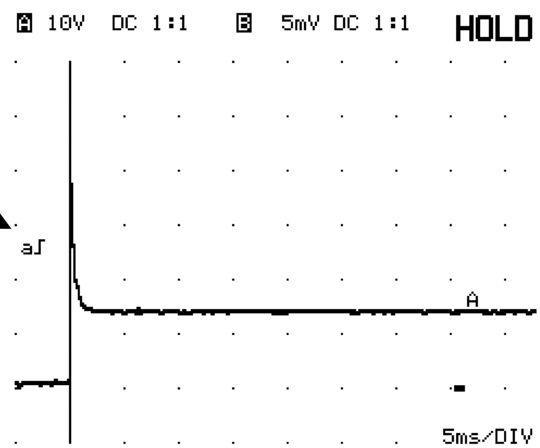
This “a” shows what voltage the trigger is set to

The negative slope symbol tells the trigger to start as the voltage goes down to that level.



Use a trigger voltage and slope that will let the pattern start near the beginning of the pattern. Use a voltage and slope that is unique to that part of the pattern. For the injector above, if the slope was set to positive, the scope would start drawing as the voltage goes up, near the end of the pattern, and you’d miss much of the info you want to see.

This trigger slope is set to positive, so the scope draws the pattern as the voltage goes up to the trigger voltage, and only gets the back part of the pattern.



To adjust the trigger, find the button that moves the trigger voltage up and down. Then you can move the trigger and watch the symbol that shows where the voltage is on the pattern. (On some scopes, you have to go to a separate screen to do this) And find the slope adjustment button. Pushing it usually toggles the slope back and forth between positive and negative slope.

Trigger can also be a time delay. This allows you to see things before the trigger point of after it. This is usually only available on the more complicated scopes. Check your scope instructions to see how to set it.

Tricky stuff about trigger. Trigger can surprise you if you are not careful. If you see a pattern on the screen, you think that’s what’s happening with the signal. But maybe it isn’t. Let’s think about this. Trigger tells the scope to start drawing the pattern, right? But if the signal doesn’t get to the trigger level, will the trigger show the new pattern, which may be zero volts? Or will trigger just keep the old pattern on the screen, and not draw a

new pattern, because the signal voltage has not come up on the right level so trigger can draw a new pattern. This depends on what trigger mode you are in.

What do you mean trigger mode? Well, the scope can be set two ways. And the different scopes use different words for it. One mode will only let the scope draw a pattern if the trigger voltage is met. This could be called “trigger mode”. If the signal is not at the trigger voltage level, the scope won’t draw a pattern. So you may see a blank screen, or you may see an old pattern, left over from the last time the signal voltage got to the level of the trigger so it could draw a pattern. The other mode is usually called “automatic” or “free run”. In this mode, the scope will always draw a picture, whether the trigger voltage is met or not. It will use the trigger voltage and draw the pattern, when the signal gets to that voltage, if it can. But if the signal doesn’t get to the trigger voltage, it will still draw a pattern. So you will see a new signal pattern on your scope. You won’t see a blank screen, or get the old pattern stuck on your screen.

Trigger mode and intermittent signals: Imagine you’ve got a problem car with an intermittent rpm sensor. The A/C signal sometimes just stops, and the car dies. You hook up your lab scope, go for a road test, and the signal drops out. If you were in trigger mode, the A/C signal will just freeze on your screen. It can’t draw a new screen, because the signal isn’t at the trigger voltage. So it may not show the signal going to zero volts because it can’t draw the new pattern of zero volts. And if you are not careful, you may think the signal is still there in the car because the pattern is still on the scope. So now the car has acted up, and you can’t see the problem. And you may start to pull your hair out. In this mode, you have to make sure the pattern is still drawing on the screen, not just stuck there because it can’t see the right voltage to draw a new pattern.

If you are in “automatic” or “free run” mode, the scope will always draw a pattern, even if the voltage isn’t right. So now, when the A/C signal drops out, the scope draws a pattern of the new voltage, which may be zero. Hurray! Now you see the glitch as the signal drops out. You don’t have to pull your hair out.

Generally, use automatic mode, unless you want the scope to start or stop with a signal going on or off.

Uses for trigger mode. There are times when this trigger mode is helpful. What if you don’t want the scope to draw a pattern until a certain thing has happened. You can set the trigger voltage to do this for you. For example, What if you want to crank the engine and measure cranking amps, but you have to turn the key from inside and you can’t reach the scope in the engine compartment to save the pattern. You set the voltage so when you start cranking, you can see the pattern. It will draw the pattern for you, and not draw a new pattern until it sees the right voltage again. So the right pattern is saved for you on the screen. (We cover this when we talk about doing a relative compression test). Or maybe you want to look at an event if the engine stalls. You set one channel to turn on when the voltage gets down to zero, which will only happen when the engine stops. (Maybe fuel pump voltage) Then you use the other channel (or three if you have a four trace scope) to watch if an rpm signal went away first, or did the relay control signal have a problem first.

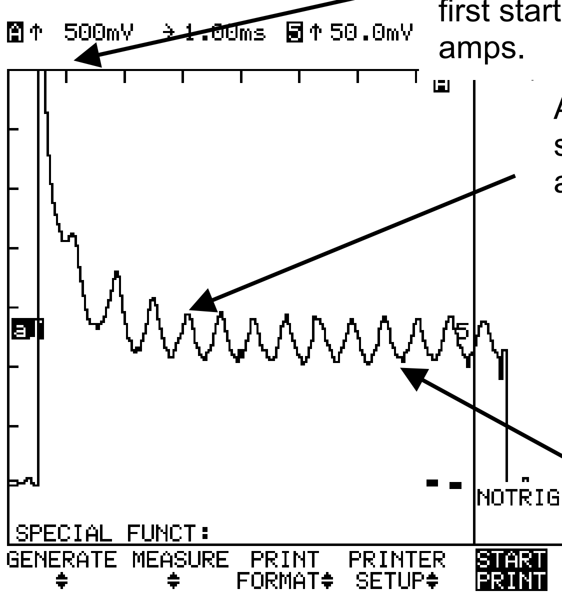
Chapter 6

Relative Compression

Well, now we get down to some diagnosis. How often have you wanted to do a compression test, but some of the spark plugs are hard to get to. You need to qualify if the mechanical part of the engine is good, but it will take a lot of time and effort to get to the back spark plugs on a V-6 engine. The engine is missing on one cylinder, and you don't know if the problem is compression related, or not. Good news—there is an easy way to test this! You can view the waveform of amperage going to the starter motor and tell if the engine has good relative compression. Here's why.

It's easy. You don't have to get to a spark plug to check the relative compression

There's this thing called **"counter electro-motive force"**, and we need to talk about it for a bit so you see how it can help you. As electricity flows through a starter motor it's not an even amount. The amount goes up and down, depending on the condition of the engine. When you first start to crank the engine, the starter isn't turning. This makes the internal resistance of the starter low, so lots of amps can flow. You will notice, if you measure it, that when you first start to crank an engine over, the starter motor draws more amps. Then, as the motor is turning, the amp draw goes down. This is because the starter motor tries to act as a generator when it is turning. It tries to push some electricity back in the opposite direction, even though it can't. (This is the "counter electro-motive force", or C.E.M.F.) This increases the resistance of the starter, and slows down the current flow.



Cranking amps are high when the engine first starts to turn over—This is over 350 amps.

As the engine starts spinning, the starter draws less amps, down to about 150 amps

There bumps show even compression from one cylinder to another.

Every time a piston comes up on compression, it slows the starter motor down, and this increases the amp flow. (Counter electro-motive force, remember)

Think about every time a piston comes up for compression. It actually slows the starter motor down. That lowers the internal resistance of the starter, so the amperage goes up. Every time a piston comes up on compression, the amp flow to the starter motor increases. As the piston goes down again, the amp flow goes down too. This creates a pattern we can watch on the scope to see if the compression is OK. If the piston came up, but there was no increase in compression, the amp flow wouldn't go up.

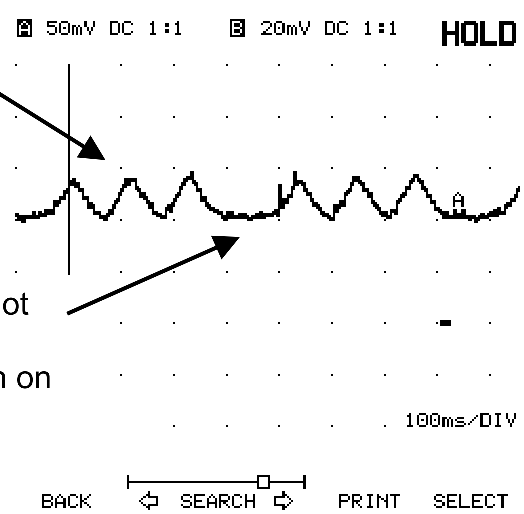
To measure this starter current, we **use a high amp probe**, sometimes called a current clamp. This probe measures the current running through the wire by sensing the magnetic field around the wire. Any time current is running in a wire, it creates a magnetic field around it. The high amp sensing probe is a type of Hall Effect sensor that turns the amperage into a voltage signal our lab scopes can read. Remember, our scopes only measure voltage. They can't sense current. 1 amp of current is turned into 1 millivolt for our lab scope.

This Current Clamp turns starter current into a mV signal your lab scope can read.
1 amp = 1 mV
or 160 amps = 160 mV

This adapter converts banana plug connections into BNC connections for some lab scopes

These peaks show each piston coming up on compression

This missing peak shows there was not an increase in compression when the piston came up—it's low compression on that cylinder



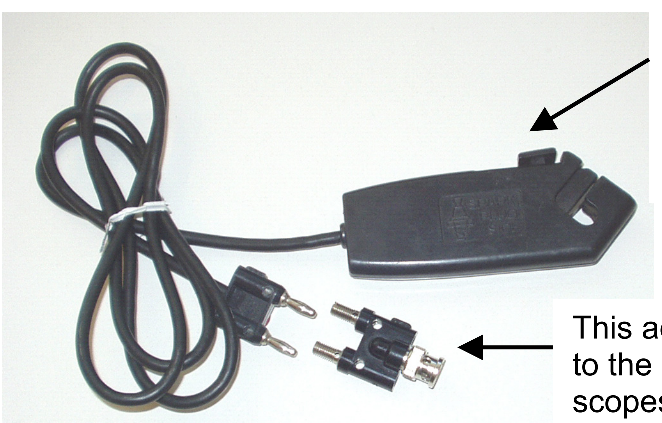
Set up your scope to read the voltage range you need. In the pattern above, the scope is set to 50 mV per division, so each division will show 50 amps of cranking current. The pattern goes up to almost three divisions, so the starter is drawing almost 150 amps. Time settings usually are OK at about 100 ms per division. You can use trigger mode to not draw the pattern until the scope sees that voltage. Then set the trigger for a positive slope, about 100 mV, so that as the voltage goes up past 100 mV the scope will start to draw the pattern for you. If you are in trigger mode, not automatic mode, the scope will hold the pattern for you after the engine stopped cranking. (see information on trigger in Chapter 5 if you are unsure of using it.)

But **how do we know which cylinder is low** on compression? Here we need a dual trace scope, one that can measure two things at once. With one channel we measure the amperage to the starter motor. But with the other channel we measure a spark pulse for #1 spark plug. Since we know when the spark pulse occurred, and the timing is the same on both channels of the scope, we can figure out the time for the different cylinders of our compression pattern. This is called using a **Trigger Pickup or Synch Probe**.

What is it? A **trigger pickup or synch probe** can be a special probe for synchronizing ignition events, or it may just be a probe designed for a multimeter so you can read RPM.

Trigger Pickup from AESwave.com gives a nice strong pulse signal

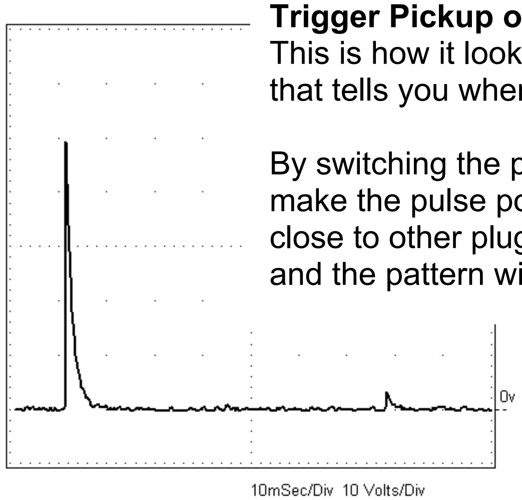
These rivets point toward the spark plug. Wrap this around a plug wire, and try to keep it away from other plug wires so you don't get multiple signals



This RPM probe was designed for a multimeter, but you can use its pulse in a lab scope to identify a cylinder.

This adapter allows connection to the BNC terminal on some scopes. If your scope uses banana plug terminals, you won't need it.

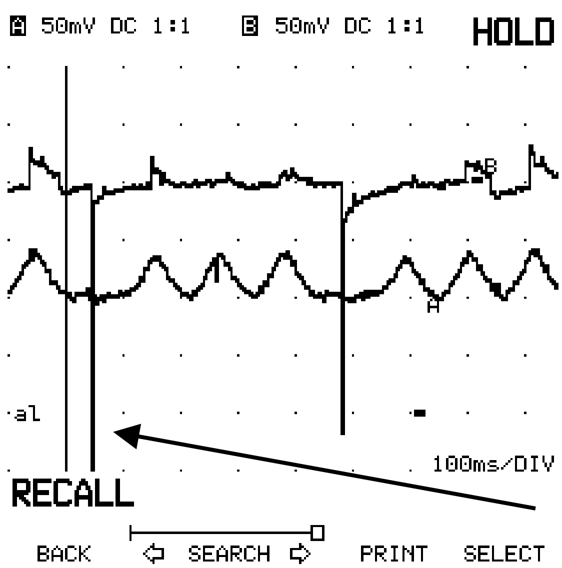
The **Trigger Pickup or Synch Probe** will give us a pulse we can use to identify cylinder #1 (or any other cylinder we want to attach it to.) Then we can use the firing order to count through the cylinders and figure out which cylinder has low compression.



Trigger Pickup or Synch Probe
This is how it looks just by itself. It's just a simple pulse that tells you when the spark plug fired.

By switching the polarity of the probe hookup, you can make the pulse point up or down. If you get the probe close to other plug wires it will pick up other pulses and the pattern will look messy.

By connecting the trigger pickup or synch probe to channel B, showing the starter current pattern on channel A, and using the firing order, we can figure out which cylinder has low compression. And we don't have to remove any spark plugs.



But how do we know which cylinder is the bad one? We can put a synch probe on an #1 spark plug wire, and put that on channel B.
No plug wire? Use the injector (on a sequential system) or primary ignition on COP. Then count through the firing order.

These vertical spikes show which cylinder is #1. (On a four cylinder engine) It happens to be our cylinder with low compression.

To do this test, we have to **disable the engine so it won't start.** There are different ways to do this. We might just take out the fuel pump relay or fuse. We might disconnect the injectors, if they are easy to get to. Sometimes, we disconnect an ECM fuse. We could also disable ignition if we don't need to use it for identifying which cylinder. Sometimes you disconnect the coil wire and ground it. With DIS systems where you can get to the

coils, you can disconnect the plug wires and put jumper wires across from one cylinder to another where the plug wires used to be. Or you might disconnect primary ignition to the coil, or series of coils. Use your judgment, depending on the type of engine you have, and what's easy to get to. Just remember to use jumper wires to allow secondary voltage to ground out. Open secondary wires that can't find a path to ground will often blow out a module or transistor.

This is only a **relative compression** test. It's comparing one cylinder to another. It's not testing the absolute compression of all cylinders. If all cylinders had low compression, you might get fooled. So this test may not be the best to find if the timing belt or chain has slipped. But it is great to determine if one or two cylinders has a likely compression problem. And it's so quick because you don't have to take out spark plugs that may be very hard to get to.

Chapter 7

Fuel Pumps

A customers car stalls as they're driving down the freeway. They pull over, use the cell phone, and get a tow to your shop. They want you to diagnosis the problem and fix it. But when you go over to the car, it starts right up. It's an intermittent problem, and it's not acting up right now. There may not be any codes that help you. What are you going to do? This test allows you to tell if a fuel pump is a likely to be an intermittent problem. It can make you look like a hero. Because a lot of intermittent problems out there are fuel pumps, and with this test you have a high likelihood of finding the problem.

This low amp probe allows us to watch the fuel pump current waveform.

Intermittent problems often show up in the waveform.

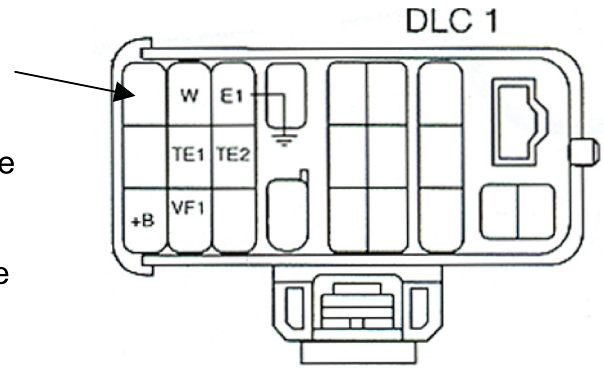
This probe has two settings:
10 mA = 1 mV   or
100 mA = 1 mV
I use 100 mA = 1 mV, and set the scope to 10 mV per division, then each division shows one amp.

Low Amp Probes: There are many low amp probes on the market now that allow us to do awesome testing we couldn't do a few years ago. This OTC measures from below one amp to about 60 amps. I use it because it's less expensive, and I can afford it. Fluke and Bell also put out good low amp probes, and there may be others. They turn amp measurements into a mV output to your scope. Many have more than one setting. So you have to do some calculations to figure out how many amps you are reading on your scope. On the setting of 100 mA = 1 mV, 10 mV would equal 1 amp. (1000 mA = 1 amp) I find this easy to use, so I often set up the scope to about 10 mV per division. Remember, the scope is reading mV from the probe, but it represents amps because that's what the probe is measuring.

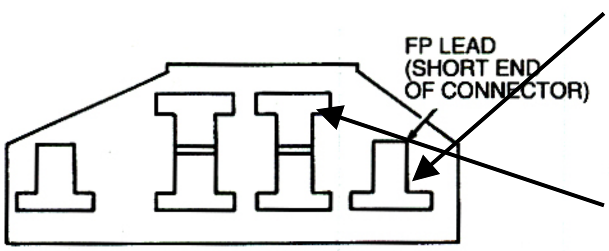
Where attach the current probe: The current probe needs to go around a wire that sends amps to the fuel pump. It doesn't matter where, as long as the current doesn't go anywhere else. You could attach around one of the wires that goes to the fuel pump under the car or under the rear seat. (Don't go around more than one wire—they will cancel each other out.) You could put a jumper wire in place of a fuse (include your own fuse to stay protected), and then attach around the wire. You could find the current at a relay.

Sometimes there are diagnosis connections with a terminal that goes to the fuel pump. (GM and Toyota do this.) On Toyotas, you can jumper B+ to FP to power the fuel pump. Then attach the current probe around the jumper wire.

Jump B+ to this FP terminal to turn on the fuel pump for many Toyotas. Many GMs have a terminal to power the fuel pump too. Then attach the low amp probe around the wire.

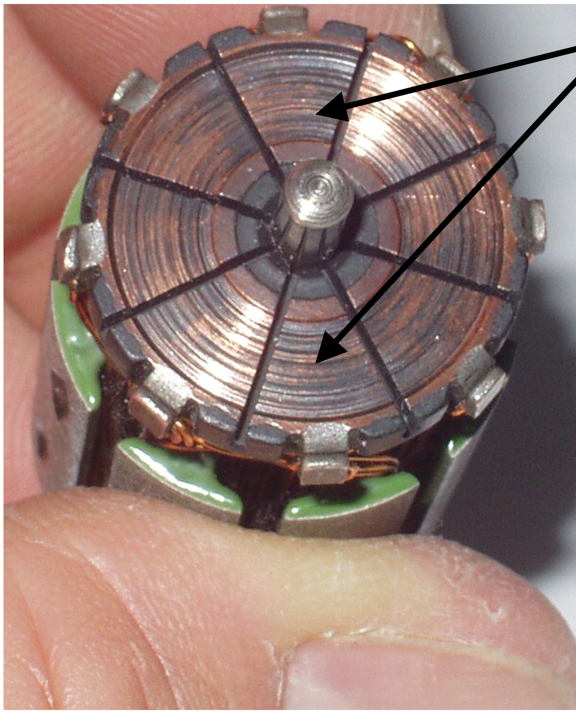


Don't forget the fuel pump has to be turned on to take these readings. On many cars you can do this without having the car running. This eliminates a lot of electrical noise.



Ground this terminal to turn on the fuel pump, but it doesn't carry fuel pump current, it just grounds the control side of a relay. You could ground it to this "signal return" wire.

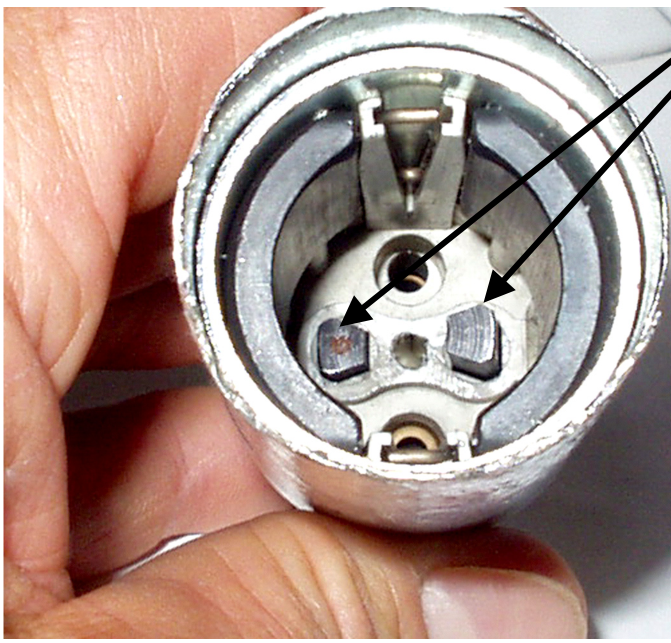
About Fuel Pumps: Fuel pumps are little dc (direct current) motors. They have little carbon brushes that run over commutator segments (contacts), kind of like a starter motor. But the commutator is usually flat like a pie, and the segments are like pieces of a pie. And there is another difference. In a starter, the brushes are big, and overlap more than one segment at a time. So the changes you see in the pattern usually relate to the resistance caused by pistons coming up on compression, not changes in contact from one segment to another. In a fuel pump, the segments are small. The brush only contacts one segment at a time. And the pattern you see often shows how the amperage changes as the brushes move from one segment to another of the commutator. As the fuel pump wears out, those segments wear and don't make good contact with the brushes. And the brushes wear out too. So you see a pattern that shows how much wear the fuel pump has. You will also see patterns that show the effect C.E.M.F. has on the fuel pump. A pump working hard against mechanical resistance, like a plugged fuel filter or worn out bushings may have higher amp flow. The speed of a fuel pump can be seen by looking at how fast the humps go by.



Fuel Pump Commutator segments are where the brushes make contact to power the motor.

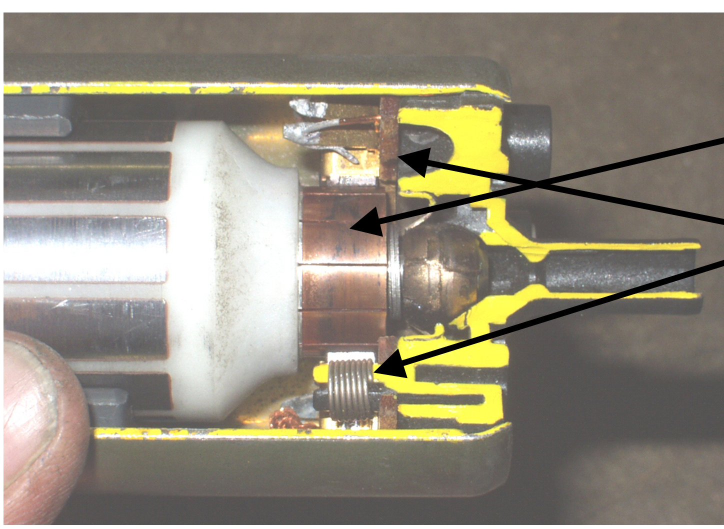
These segments get **worn and burnt**, and make poor contact with the brushes. These caused an intermittent driveablility problem.

This commutator has 8 segments, so you could see the pattern repeat every 8 humps.



These **Fuel Pump Brushes** make contact with the commutator segments to power the fuel pump motor.

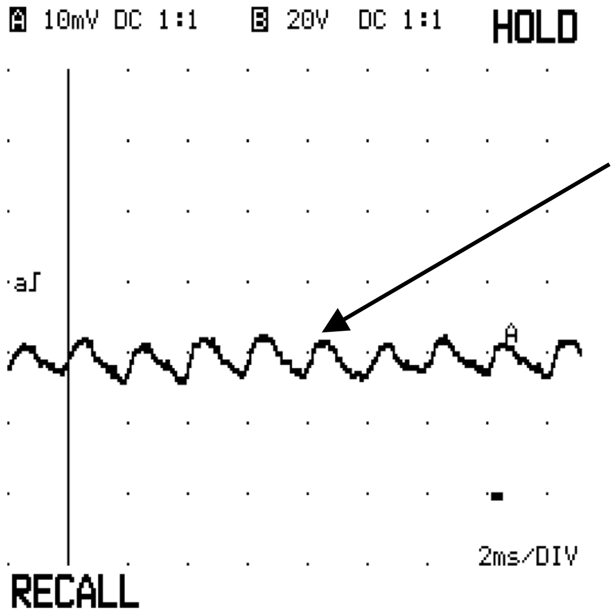
Notice the wear on these brushes. This wear helps cause the intermittent problem.



Another fuel pump design

See the commutator segments that are starting to burn.

Brushes are here and here.



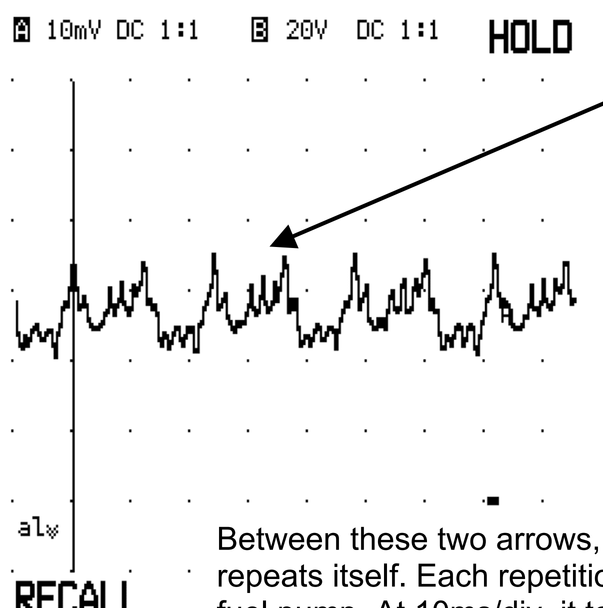
Good Fuel Pump pattern

If the contacts are all good and even, the pattern creates even humps as the brushes go from one segment to another on the commutator plate.

With probe set at 100 mA = 1 mV, and the scope set at 10 mV/div, each division shows one amp.

This low pressure pre-pump is taking about 2 amps draw.

In preparation for a class one day, I captured the waveform of my wife's Crown Victoria fuel pump. I thought it would be a good pattern. My wife had not said anything about how the car was running. When I looked at the pattern, I saw all these uneven humps that indicated a bad pump. I asked her "Honey, have you had any problems with how your car drives lately?" She replied "Oh, yeah. Sometimes it's real slow getting on to the freeway. But I didn't want to tell you, I know you've been busy lately." I had a friends shop replace the pump. The pattern of the new pump was much more even. And my wife said her car always had plenty of power now.

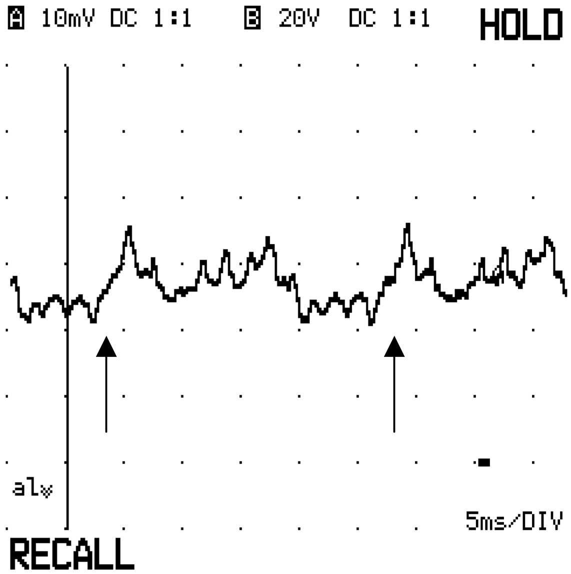


Bad Fuel Pump Pattern

Notice how uneven the humps are in this pump. This shows a problem with the commutator segment contacts.

This was an intermittent problem (in an '88 Crown Victoria). Sometimes there was a lack of power getting onto the freeway.

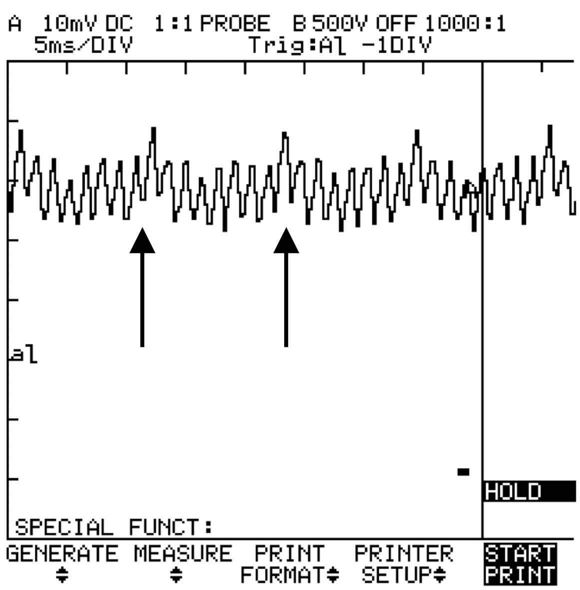
Between these two arrows, you can see a pattern that repeats itself. Each repetition is one revolution of the fuel pump. At 10ms/div, it takes about 25 ms for this



By spreading out the time to 5ms/div, we can spread out the pattern and **see the repetition** more easily.

Notice, it takes about 25 ms for the pump to rotate one time and repeat the pattern.

Pattern repeats from one arrow to the next.



After replacing the pump the pattern is much more even. (It's not perfect, but it was probably an aftermarket pump)

Notice the new pump is turning faster than the old pump. It only takes about 12 ms for the pump to rotate once.

The new pump draws about 5 amps, the old pump was about 3 amps. (Poor contacts wouldn't conduct enough electricity to power the pump enough.)

There is no lack of power now, and no intermittent problem.

Chapter 8

Primary Ignition Voltage

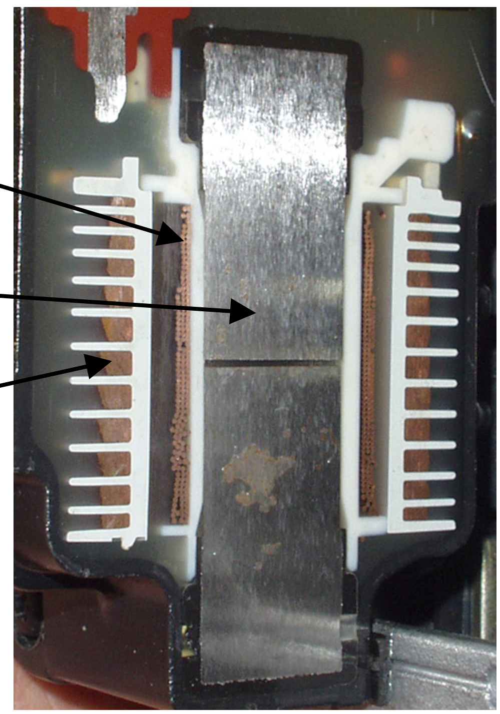
By primary ignition, we mean the **low voltage part** of the ignition system, the part that uses battery voltage. The spark that gets generated by this low voltage system becomes very high voltage, but that's secondary ignition. We'll get to that later. We'll start talking about the low voltage system. Later in the chapter we'll discuss amperage patterns, also called current ramping.

Cut away look at high energy ignition coil:

Primary windings to create magnetic field.

Iron core to focus the magnetism as the magnetic field is collapsing.

Secondary windings to pick up moving magnetic field and create high energy for spark.



Let's first talk about **how we generate this spark** for our ignition systems. We use the principle that a magnetic field moving across a wire will generate electricity. We have a coil. (Really a transformer, but we call it a coil.) This is thin wire that's wrapped round and round. By running battery voltage through the coil of wire we generate a magnetic field. The magnetic field is strengthened by having many wires wrapped together. We also have iron near by. Magnetism finds it easier to flow through iron than through air or other things. So, by having an iron core or iron frame to our coil, we focus the magnetism to flow in just the places we want. Then we are going to turn off the flow of electricity through these wires by switching off the ground. This causes the magnetic field to collapse very quickly and give us a moving magnetic field. Then, on the inside of our first coil of

By switching off the ground, the magnetic field collapses. This creates a magnetic field that moves across the secondary wires. This generates the spark. This is how they all work… It's really very simple.

wire, we have a second coil of very fine wire, with lots and lots of windings. The collapsing magnetic field is moving past these very fine wires, and we generate an electrical spark in these very fine wires. This is connected to our spark plug, and presto, we've got spark.

This is how every ignition system works, with only a couple of exceptions. There are some Porsches and motorcycles that use what is called a **capacitive discharge system**. Instead of ungrounding the coil to collapse the magnetic field and create a spark. These systems suddenly power the coil to create the moving magnetic field and generate a spark. Similar, just slightly different. Evidently, this works better for systems that are likely to foul the spark plugs. But every other system out there uses this simple concept of ungrounding the coil to generate a spark. So don't let these systems scare you with their complexity. They are all really simple. And you understand how they work. Whether it's a conventional system, with one coil and a distributor that sends spark to different plugs. Or a DIS system where one coil fires two plugs. Or a COP (coil over plug) system, where there is a single coil for every spark plug. The primary side of all these systems works the same. By ungrounding the circuit, the magnetic field collapses, and the spark is generated.

The **primary wiring** to the coil or coils is not that complex either. (With some variations.) We need to talk about it so you understand where to connect your scope. Basically, you have a positive wire and a negative wire that goes to the coil. You have a positive wire that caries electricity from the B+ of the battery or alternator, and you have the negative side that is switched on and off. The B+ side often comes through the ignition switch, or it may come through a relay. And the negative side may be grounded in a variety of ways. It might have simple points (Remember those? Some of the young guys have never even seen them…) Or it will have an ignition module that contains a transistor to turn the circuit on and off. It might be called an igniter on some Asian vehicles. Or it might have the switching transistor inside the PCM. However they do it, there is just one negative side wire for every coil. And that is the wire you tap into to look at the primary ignition pattern.

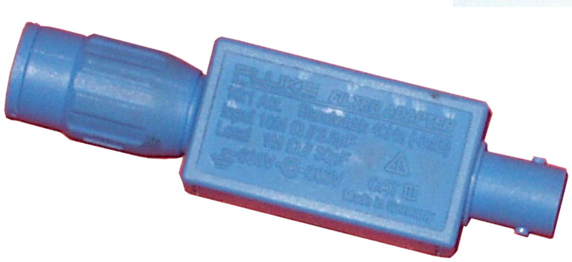
There might be some other wires going to the coil. Let's understand them too, so they don't confuse you. On some single coil systems, like GM, there may be an extra negative wire that runs through a resistor. It can be an RPM signal wire used for the PCM or dash tachometer. And on DIS or COP systems, there may be more that two wires for each coil because each coil is paired with an electronic module. And the module needs signal inputs to tell it when to fire. So besides a positive and negative wire going to that coil, there can be signal wires from a PCM or RPM signals that help the module know when to fire. And there might be ground wires to complete the circuit for these signal wires. But if you can get to the coil itself, one of these wires will be the switching ground that you need to watch. You might have a problem getting to the ground wire is on some vehicles where the coil is inside the distributor with a module so the switching takes place on the inside and you can't get to the switching wire unless you break into the distributor. Or the module can be mounted under the coils, like GM DIS, and you can't get to the coil wires without taking off the coil. On these, try doing your diagnosis with the secondary pattern, since it's easier to get to.

When you connect to the negative side of the coil, I recommend you **use a 10:1 filter** to lessen the voltage spike to the delicate electronics on the inside of your lab scope.

Remember, primary ignition can spike up to several hundred volts, even though it starts out at 12. The spark that is generated for the secondary system is mirrored on the primary side too. That spark can sometimes jumble your lab scopes memory a bit. So if you use a 10:1 filter, that 400 volt spike becomes only 40 volts of energy to the scope. And the scope is safe.

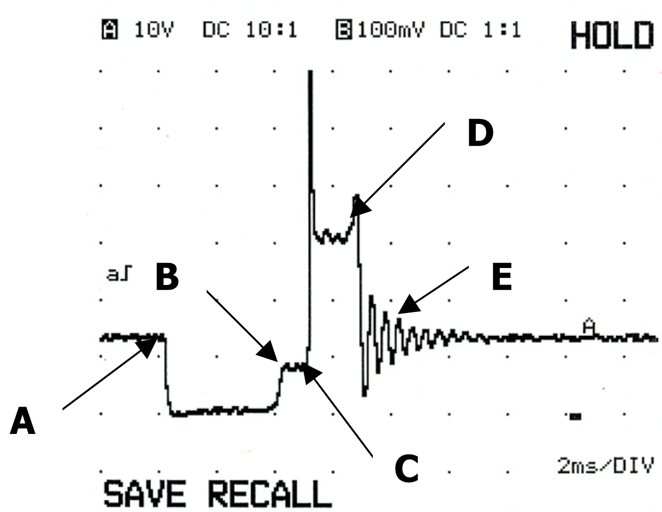
These **10:1 Filters** reduce voltage spikes to protect your scope

Only one tenth the voltage now gets to your scope, unless you set it for 10:1



Some scopes have built in protection that can fool you if you aren't careful. Like the UEI 7100 or LS 2000. They have an internal zener diode to protect them. If the scope sees the unfiltered high voltage, it grounds out the signal, and the car stops running. (And you don't see a pattern.) And you may go, "Duh, what happened?" If you put on a 10:1 filter, the scope won't ground out the coil, and the car will keep running.

When you hook up your scope, the red wire goes to negative side of the coil, and the black wire goes to a good ground. And, if you get the wrong wire, it won't hurt anything, as long as you are not tapping into the secondary high voltage that goes to the spark plug. (But don't touch the wire with bare hands, the voltage can be rather high. It can stop your pacemaker. And the amperage could be kind of high; that's a problem)



Now let's talk about **what the scope pattern means**. We'll start with a normal good pattern.

“A” is the point where the voltage starts to be grounded to build up the magnetic field. Notice, the voltage **before “A”** shows the battery voltage going to the coil. Usually this should be close to battery voltage or charging system voltage. Even though this is on the negative side of the coil, you see battery voltage when the system is not grounded. (There is no voltage drop if there is no amperage flow.) On some older point systems, this voltage goes through a ballast resistor before it gets to the coil, so it may be only about 10 volts. (This is to keep the coil from getting too hot.)

After “A” the voltage drops to almost zero because the voltage is used up pushing through the resistance of the coil. Watching that this voltage has dropped to almost zero is important. If the voltage doesn’t get close to zero, it means there are other resistances in the circuit sharing the voltage push. And they are probably a problem. Like a bad transistor or poor connection. These can prevent enough amperage flow through the coil, so you don’t build up enough magnetic field for a strong spark.

“A” to “B” is where the coil has been grounded, and we have built up a magnetic field that is now big enough to generate a spark. Some modules and PCMs will time this grounded time and know we have grounded enough, so they put in a resistor to limit current flow. This keeps the coil from getting too hot, like a ballast resistor.

“B” shows this current limiting hump. Some systems will not have this, and that is OK.

“C” is where the ground is turned off and the magnetic field collapses. This creates a moving magnetic field and we generate spark.

“A” to “C” is the total time we grounded the coil, and this is called **dwell** time, or **saturation** time. This has to be big enough to generate a spark. If you hook up a dwell meter, this is what you would read. But it might show degrees (º) or percentage (%) instead of milliseconds (ms). Some meters may not be good at seeing the extra time from B to C, they may only see A to B.

“C” mirrors the spike that was created to jump across the spark plug gap. It is an indication of how big a gap the spark had to jump. But we don’t usually measure that on the primary side of the ignition; we usually use that on the secondary side. This spike often goes over 200 volts, and can go as high as 400-600 volts. It can tingle, or it can even hurt you on some vehicles, so handle this negative side of the coil with something insulated. Don’t just go stick some metal in there and touch it with your bare fingers. When I was much younger, I wondered why this negative side would tingle or hurt, especially when I was sweaty. Now I know.

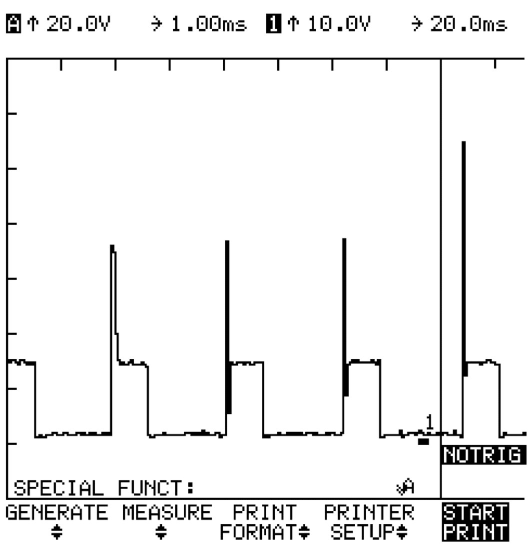
“C” to “D” is the time spark is flowing across the spark plug gap. It’s called **Spark Duration.** This is important. We can do a lot of diagnosis with just this. If something changes in the spark circuit, there is usually a change in this time. It’s really cool. We’ll talk about this in a bit. This can be used for diagnosis when you can’t take a reading of secondary ignition for diagnosis, like some COP systems.

“E” shows the coil oscillations. Many guys were trained to use this for diagnosis, but it’s really not that important. It used to be that you have to have 4 or 5 oscillations or you had

a weak coil. But with today's systems that control dwell time it just doesn't show much. I have seen many new cars that had only 1 or 2 oscillations, and they were just fine.

Using Spark Duration for diagnosis. We have to cover some **theory first**. Think that we have energy generated in the coil to go to the spark plug. If everything is normal, there is a normal amount of time that the spark flows across the spark plug. Usually this is 1 to 2 ms. One ignition tester gave a specification of 0.8 to 2.2 ms. and I have found this to be fairly accurate. But if there is a problem in the circuit, there is usually a change in the duration time. And we can use this to help diagnose the problem. For instance, what if we have high resistance in the plug wire. It takes more energy to push through this, so there is less energy left over to maintain the spark for a long time. So the **duration will be less for high resistance problems**. These could also be resistance in a coil wire, large gap at the rotor or spark plug, etc…It could also be a lean air-fuel ratio in the combustion chamber. As air tends to be an insulator, this causes more resistance. A weak coil would also make the duration shorter. So could low voltage to the coil, or a bad ground.

The opposite is also true. The spark **duration will be longer for low resistance problems**. If the plug wire was grounded out on an exhaust manifold, the resistance is now smaller than normal in the circuit. And there is more energy left over to keep the spark flowing, so this causes the duration to be longer. Another low resistance problem could be spark plugs that are fouled by oil, carbon or gas deposits. These allow the spark to flow through the material instead of jumping the gap and they make the duration pattern longer. A rich air-fuel ratio will also cause a longer duration because the extra



This is how primary ignition may look if you don't narrow down to look at one cylinder at a time. You may not get much detail, and you don't know which cylinder is which.

(This is recording 1 at 10v/div and 20ms/div.)

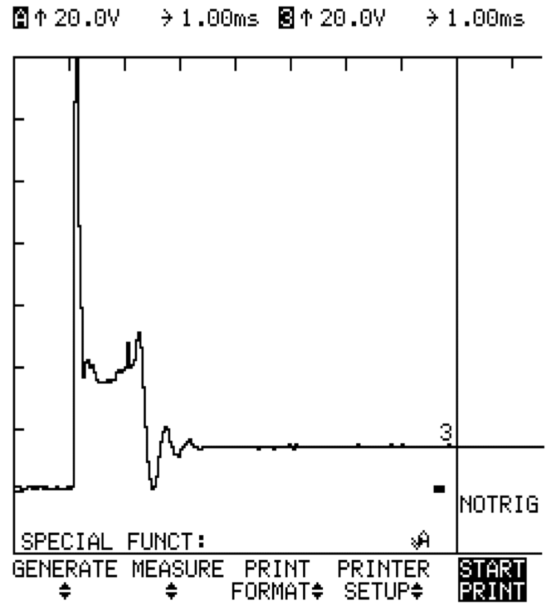
fuel acts as a conductor, making it easier for the spark to travel.

The type of system you have will affect what is normal for your spark duration. For instance, an old point ignition system may normally have a fairly short duration. 0.9 ms may be normal for one of these. Or a modern DIS or COP system may have a longer duration, like 1.7 ms, because it has so much energy.

If we expand the time, we can get more detail on one cylinder.

At 1 ms/div we clearly see the spark is about 11/2 ms long. This is perfectly normal.

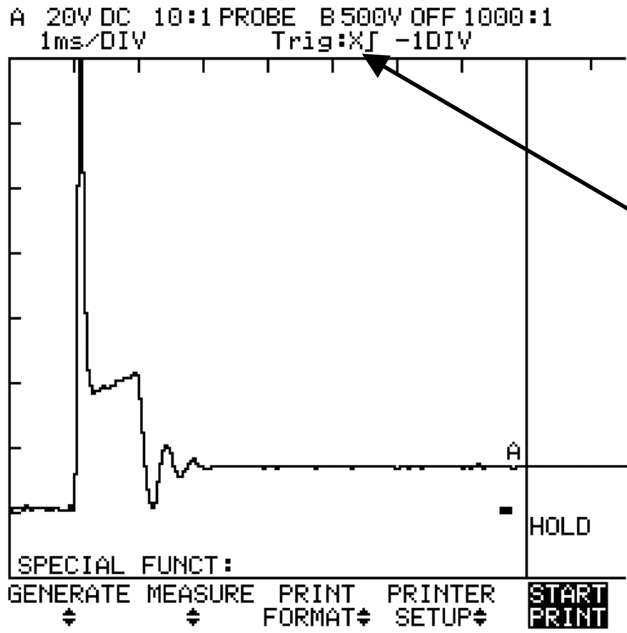
But without a trigger, we don't know which cylinder we are looking at.



These RPM probes designed to be used with a DVOM can be used to trigger ignition patterns.

Place the probe around a plug wire for the cylinder you want to see or start your pattern with. You can move from plug wire to plug wire and check all cylinders quickly.

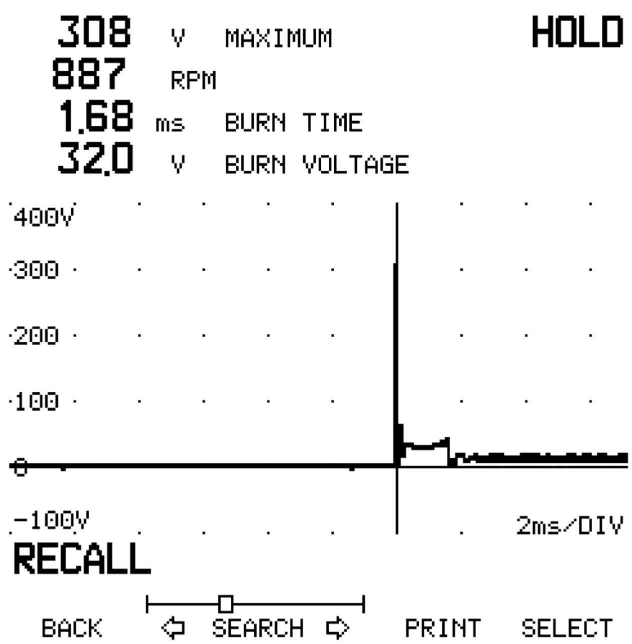
Sometimes these are called 1000:1 probes
Note the BNC adapter.



Using the RPM trigger discussed earlier for relative compression, we can know which cylinder we are looking at.

This Fluke 97 is set up for external trigger. Then it will trigger off the pulse from the RPM sensor attached around the plug wire you want to read.

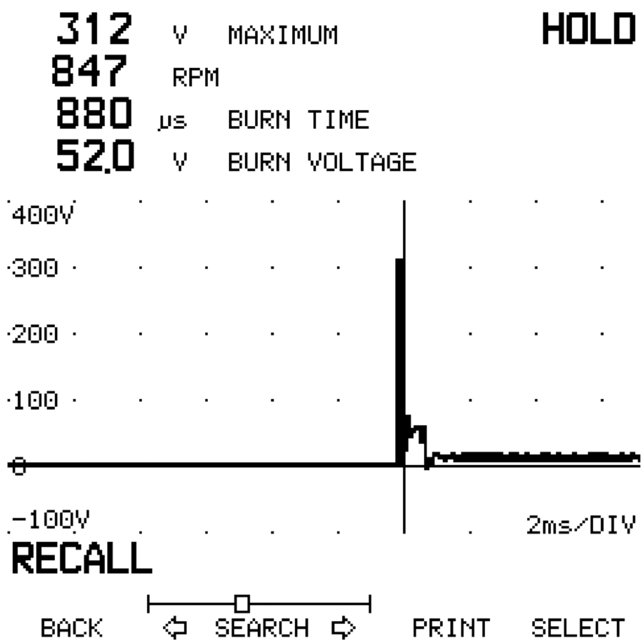
On other scopes, you might have the RPM sensor on channel 1 to trigger, then watch the primary ignition pattern on channel 2



This **primary ignition pattern** from a Fluke 98 does show us the burn time (spark duration) and it tells us with numbers. Very handy, but we don't need the numbers.

Spark duration of 1.68 ms is normal.

The ignition pattern and spark duration will give you an idea as to whether the spark time is normal, too short or too long. If the time is too short you will look for high resistance problems, or problems that limit the power of the coil. If the time is too long, you will look for low resistance problems. The pattern is only an indication of where the problem might be. You use other diagnostic techniques to narrow down what the problem is.



This pattern had a spark tester applied to the end of the plug wire, acting like a spark plug with a very wide gap.

This high resistance problem showed up as a short spark duration (burn time) of only 0.88 ms.

Chapter 9

Primary Ignition Amperage, or Current Ramping

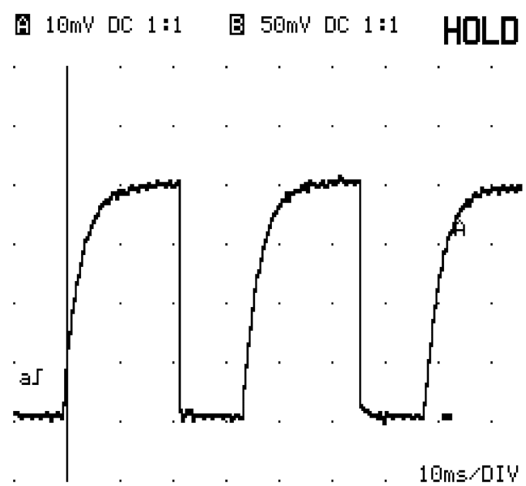
Looking at voltage is only part of the picture of what's happening with the ignition system. (No pun intended.) Another part is amperage. To really know what's happening in a circuit, we need to be able to measure the amps too. And now we have some awesome tools to do just that.

When the coil is grounded, the current flows in and builds up the magnetic field. But how long should it take for the current to flow in? Electricity flows at the speed of light, right? So why does it take some time to build up to the maximum amp flow? The wires inside the coil aren't that long.

Why should it take some time to fill up the coil with amps? Doesn't electricity flow at the speed of light?

This coil takes 10 ms to get to full amp flow of 4 amps. (Much slower than the speed of light)

With the probe set at 100mA = 1mV, then each division is one amp.

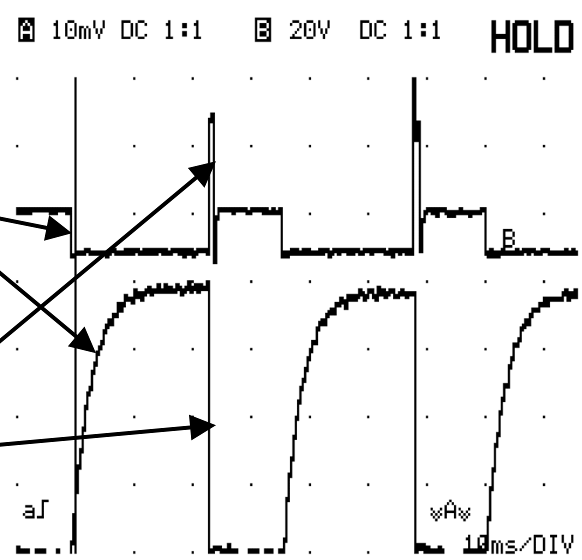


The answer is **counter electromotive force**. (CEMF) As current flows into the coil, it builds up a moving magnetic field that tries to force current in the opposite direction.

Top pattern is primary ignition volts, bottom is primary amperage (current)

As the voltage drops when the coil is grounded, amperage "ramps up"

The voltage rises to fire the spark plug when the amperage drops off suddenly. (Magnetic field collapses)



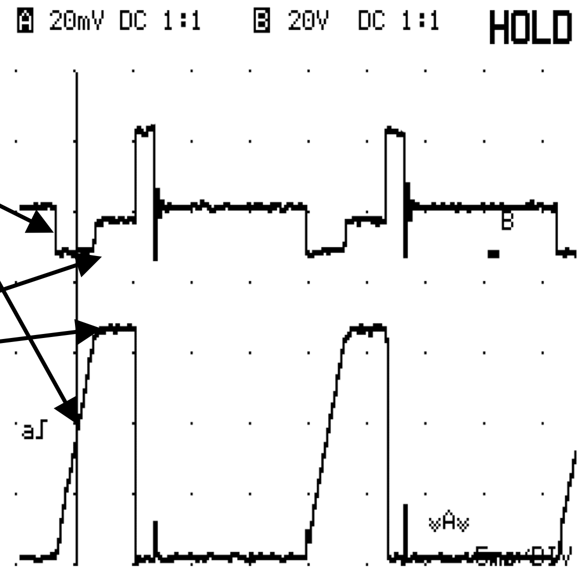
This CEMF slows down the flow of amps into a coil. When amperage fills a coil, there is a characteristic shape to the curve of the amperage flowing in. We call it the “current ramp”. It’s like a fingerprint. No two designs are the same, but there is a general shape to the ramp that will begin to look familiar to you. Some are more curved, some are more straight. Some even seem to bow backwards. But you can see there is some time before maximum current is reached in the coil. When there is a problem with the flow of amps in the coil, you will see a change in the shape of the current ramp. You use these deviations from normal in your diagnosis to figure out what’s going on.

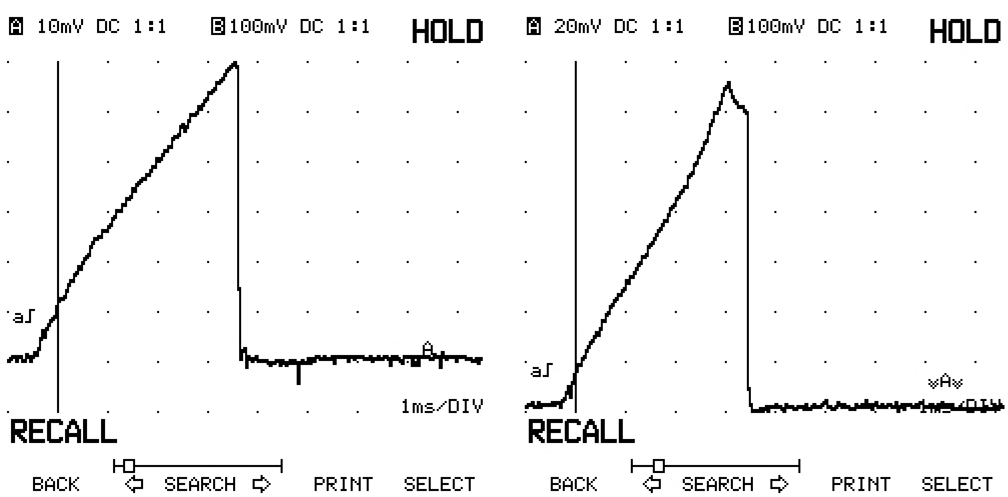
Computer Controlled Dwell (Top is voltage, bottom is current)

Notice the current ramps up steeply when the coil is grounded completely by the ignition module.

When the voltage comes up partly (a resistor has been added to the circuit) the current levels off at about 6 1/2 amps.

The ignition module is controlling dwell and amp flow to keep the coil from overheating.





Other Current Ramping Shapes
The Toyota DIS coil (at left) has a different shape than the Chrysler COP below. And these are different than the Ford distributor system above. This is normal.

To measure this, use a low current probe, just like the one we used to look at fuel pumps, and wrap the sensor around a wire that carries current to or from the coil primary. (Not both at once—they would cancel each other out.) Since current is the same everywhere in a series circuit, you can wrap the current probe around either a positive wire going to the coil, or a negative wire coming from the coil. Both will show correct amperage if the amps are not going somewhere else too. I select the 100 mA = 1 mV position. Then 10 mV on my scope equals 1 amp. So I select 10 mV/div. Normal amp flow for coils is usually 4 to 8 amps. Newer coils that develop more power usually take more amps. Be sure to spread the time out enough on the scope to get a good look at the ramp. You want to see some detail.

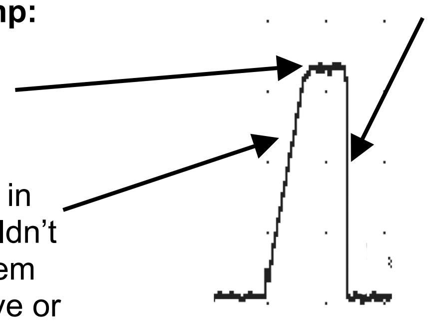
What to look for:

1. You want to see a **curve or ramp** as the current flows into the coil for adequate saturation. If the current doesn't rush in too fast, it shows the windings of the coil are probably OK. (They create the CEMF.) If the line goes straight up, the wires are shorting out, as they tend to do. The electricity wouldn't be flowing through all the coil wires and it wouldn't build up the magnetic field, or counter electromotive force (CEMF), that slows down the current flow.
2. For systems that have an ignition module or computer that limits current flow, you want to see the **ramp not go too high, or too low**. This shows the current limiting capabilities are working. If there is too much amps flowing through the coil, it will overheat the coil after a while and the coil will go bad. For coils that aren't current limited, you can see the resistance limit current flow and know the resistance of the coil is OK.
3. Inside the coil **the amps should shut off suddenly**, so the magnetic field can collapse quickly enough to generate a strong spark. If the amps shut off gradually, the magnetic field would move slowly, and this would generate a weak spark or no spark at all. So you want to see this line go directly down.

Review what we can tell from a **normal good current ramp:**

Ignition module is limiting amperage at proper level

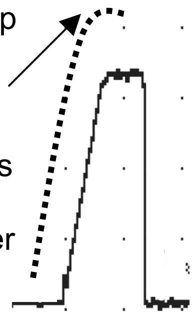
Ramp up shows the coil is in good shape or CEMF wouldn't work normally. (Each system has it's own individual curve or ramp shape.)



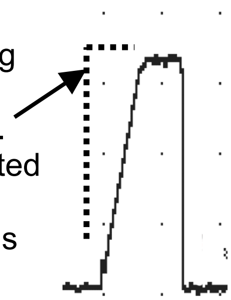
Current cut off in module or transistor is sudden enough to generate a strong spark.

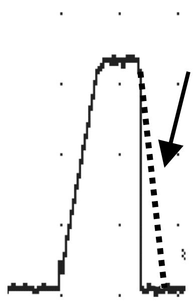
Possible problems to diagnose from current ramping:

If the curve ramps up OK, but it goes too high, a bad ignition module may be limiting the coil amps too high. This would burn out the coil over time.



If the current ramp came straight up, it shows a bad coil is shorted on inside and not developing the CEMF to slow down current flow. Current being limited shows the ignition module is doing it's job.



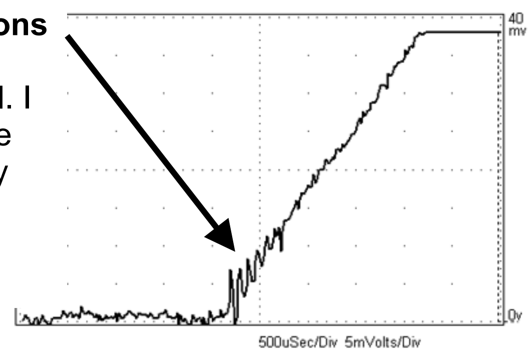


If the coil cutoff is too gradual, the amp flow isn't stopped suddenly enough in the coil. The moving magnetic field won't be strong enough to develop a strong spark. autonerdz.com gives an example of fuel pump relay connected to the coil that caused this.

Using Coil Turn-on and Turn-off Oscillations: I just learned a couple of tricks from attending Jim Linders drivability Guru School in Indianapolis.

Coil Turn-On Oscillations

These coil oscillations show a coil is good. I zoomed in by making my time and voltage divisions smaller, and then readjusting my trigger. A bad coil will show weaker oscillations, compared to a good coil.



Turn-on oscillations are a clue to coil strength. When the amperage starts to flow through the coil, there are oscillations that can be seen when you have a normal strong coil. If the coil is weak or dead, there will be less or no oscillations. So this can tell us if the coil is good. You often have to zoom in on the coil turn-on signal to see these oscillations. You have to be good with your trigger. And I had not been seeing these for years because I didn't have the right adapter. I was using a low amp probe that had a metal BNC connector, but my Fluke 97 and 98 both had plastic BNC connectors. There is

an incompatibility here. The metal BNC adapter was dampening an AC part of the signal. I had to get a plastic BNC adapter from aeswave.com so I was connecting to my Fluke with a plastic BNC connector. Then, “Hello”, I could see much more of these oscillations.

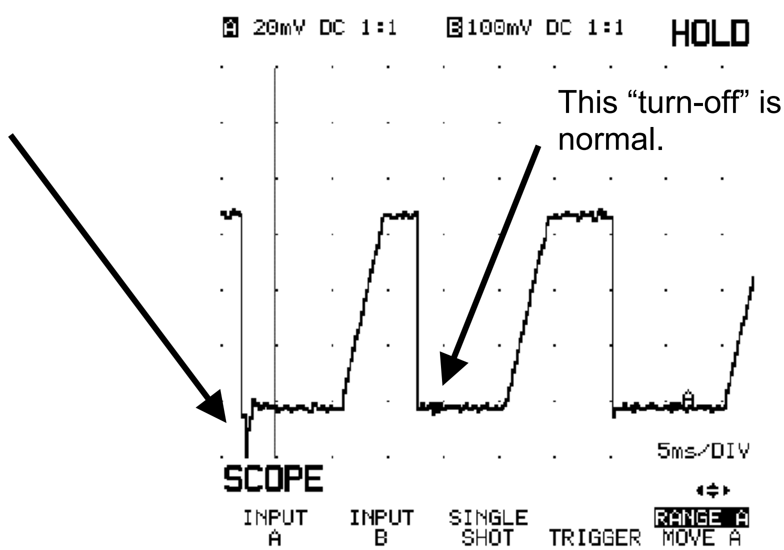
Don’t forget, you can still use a ST-125 or similar **Spark Tester** to test for coil strength. If the coil will force a spark across the big gap in the spark tester, you know the coil is strong enough to run the engine. Use the small gap testers for the older round coils that are not as strong as the new systems. And use the large gap testers for the newer high energy coils that are often square looking.

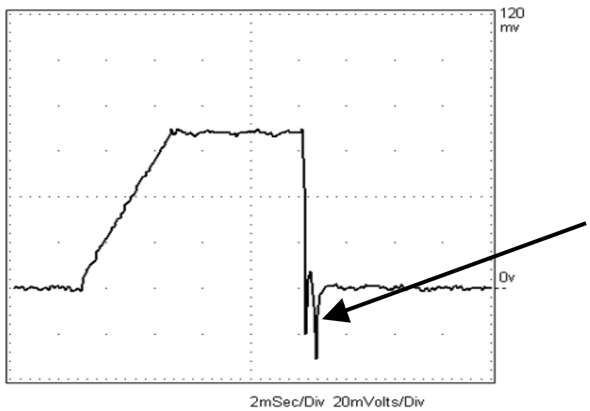
Watching coil turn-off for ignition high voltage problems: There’s another area of the ignition coil ramp we can get information from. If there is a larger than normal high resistance open or gap in the secondary ignition, it will change what you see at the end of the coil pattern. There will be a bigger downward spike, or there might be extra oscillations that slope upward. As the coil magnetism fires the spark plug, a larger gap creates higher voltage. And this higher voltage bounces magnetically, creating a kick that you can notice when you know to look for it. If you have the right equipment you can zoom in on this part of the signal and get more detail. With my metal BNC connector, I had to have a big problem before I could see a turn-off kick or spike. With the plastic BNC connector, I see more oscillations. Now I have to use experience to see how much is too much. It’s good to create a problem with a spark tester, then compare a good cylinder with a bad cylinder to see how the larger gap shows more spike on your equipment. John Thornton describes how an open circuit will create oscillations sloping up. But a normal cylinder has the oscillations getting smaller in a straight horizontal line.

This “turn-off” has a big downward spike, showing a big gap in the secondary ignition somewhere.) And the oscillations slope up as they get smaller.

This cylinder was isolated by triggering with a synch probe on that cylinder.

This was captured with the metal BNC connector so it doesn’t show as many oscillations as you see with the plastic BNC connector.

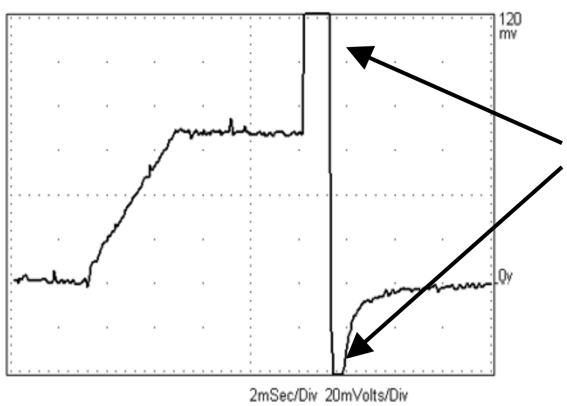




High voltage ignition problem, viewed with a metal BNC connector on Fluke 97.

These downward spikes show there is a big gap in the ignition, created by my spark tester.

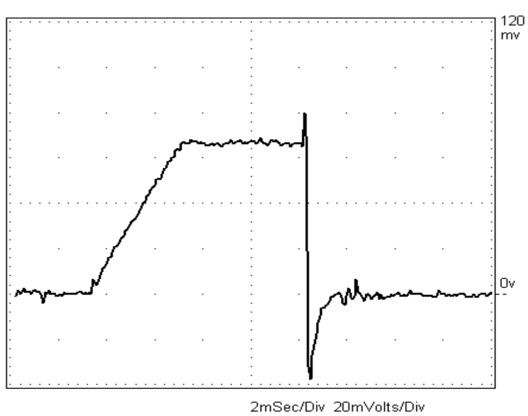
I used a synch probe to focus on the bad cylinder.



Same problem as above, but viewed with a plastic BNC connector on my Fluke 97.

Big upward and downward spikes show the big gap and high firing voltage in this coil amp pattern.

You've got to experiment with your scope and adapters to see how problems will look on your equipment. Depending on your equipment, the same problem can look different.



Normal ignition voltage, but on my Fluke 97 with the plastic BNC connector that is more sensitive. Same vehicle as above.

If I didn't know what normal looked like on my equipment, I could mistake this pattern for a problem.

How can you use this? With many systems you can look at secondary voltage, as we will do in the next chapter, and do your diagnosis from that. Or, if you can't get secondary voltage because it's hard to get to, you might be able to see the problem with primary ignition voltage. But there are COP (coil over plug) systems out there where you can't get either. The ignition module or igniter might be on top of the individual coil, so

you have trouble picking up the magnetism with an adapter or foil tape. And with the module on top of the coil, you often can't tap into the negative side of the coil to read a primary ignition signal. So you are left with no way to read ignition voltage. But you can tap into the current for the positive side of the primary ignition. And by watching the coil turn-off signal, you can see if there is a likely high voltage ignition problem. So if a spark plug has a wide gap from some damage, or the boot going down to the plug has a gap problem, you would know to do a visual inspection.

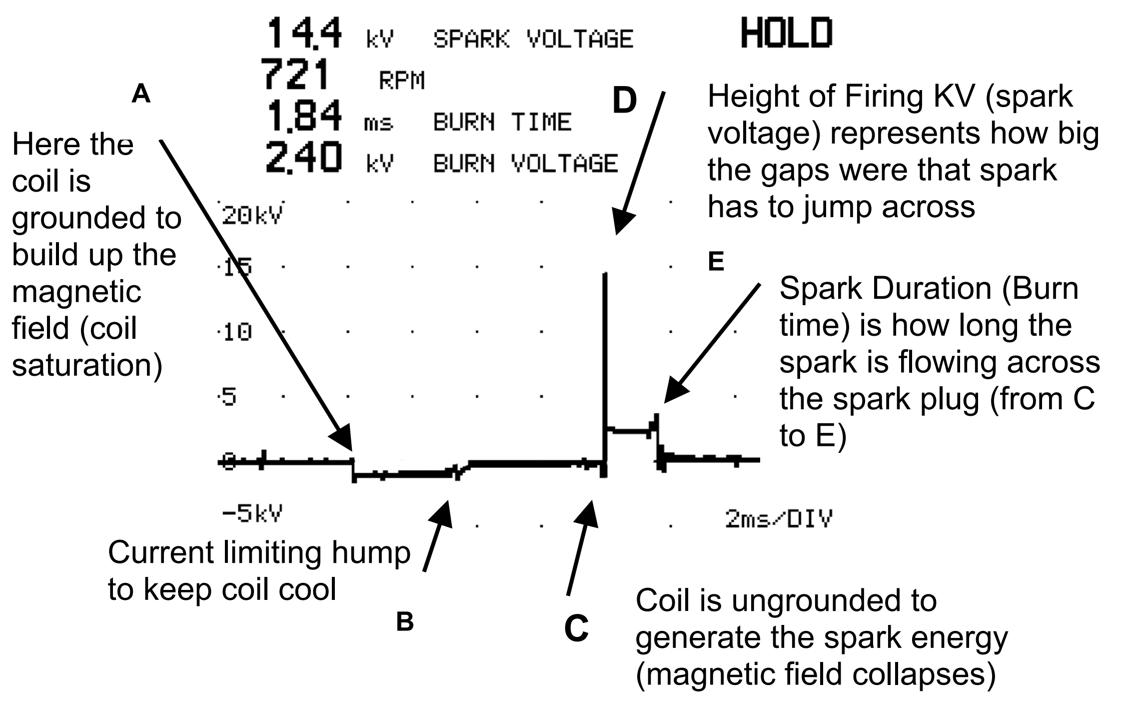
Chapter 10

Secondary Ignition

Now let's talk about secondary ignition. This is the **high voltage** that is generated to go to the spark plug. When we diagnose this, we can compare how high the firing KV goes, how long is the duration of the spark, and the shape of the spark.

First, **a little more theory**. Let's look at a single **basic secondary ignition pattern**, and talk about what is happening at different places in the pattern. The secondary pattern looks almost like the primary pattern, only the voltage range is different. Big box ignition oscilloscopes may show many cylinders together as a parade (or display), raster (stacked), or superimposed pattern. These may look different from what you see here, but these are just different ways of showing basic patterns for each cylinder. Once you understand what is happening in a basic pattern, you can look at the different variations and they will make more sense.

Secondary Ignition looks almost like primary ignition, only the voltages are different.



"A" is where the coil is grounded to build up the magnetic field used to fire the spark.

"B" is the current limiting hump, where a resistor is put in the circuit to limit current flow and keep the coil cool.

“C” is where the coil ground is taken away, magnetic field collapses, and spark is generated.

“D” is how high the spark voltage goes to push across the spark plug gap. This is automatic, the voltage goes only as high as it needs to go to push across what ever gaps there are in the circuit. 8 – 15 KV is normal.

From “C” to “E” is the spark duration. This is how long the spark flows across the spark plug gap. If it doesn’t flow long enough, the spark doesn’t do a good job of igniting all the gas in the combustion chamber. Then we don’t have good combustion. If it flows too long, something is usually wrong in the circuit.

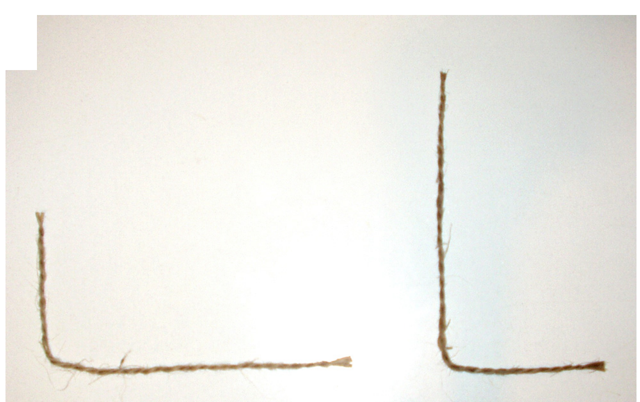
In primary ignition, we talked about how the spark duration would be longer for a low resistance problem, like grounded out plug wires and rich fuel mixtures. And the spark duration would be shorter for high resistance problems, like wide plug gaps, high resistance in wires, or lean mixtures. In secondary ignition, we are still going to use these readings. And remember a normal pattern is usually 1 – 2 ms in duration. But in secondary ignition, we are going to add the height of the firing spike into our diagnosis. We call this firing KV (K or Kilo for thousand, V for volts.) KV is Kilovolts. It’s the voltage required to push the electrons across the spark plug gap. And it’s usually about 8 – 15 KV.

The **firing KV** goes as high as it needs to so the voltage is strong enough to push the electrons across the spark plug gap, or whatever gap is in the circuit. It could be the wrong rotor was put into the distributor, so the rotor air gap is very large now. Or maybe the wire or boot that sends the spark to the spark plug has gaps in the conductor. Maybe the plug wire is coming out of the distributor cap. Whatever, we can use this number as part of our diagnosis.

There is also a relationship between the spark duration and firing KV. We will use this in diagnosis. I call this **string theory** (It’s only distantly related to the string theory used in physics to describe behavior inside worm holes.) It says that we only have so much energy generated in our coil for the spark. If we use up more than a normal amount of this to jump across the plug gap, we have less than a normal amount to continue the spark duration. Or, if we use less than normal amount of energy to jump the plug gap, then we have more than normal left over for a longer spark duration.

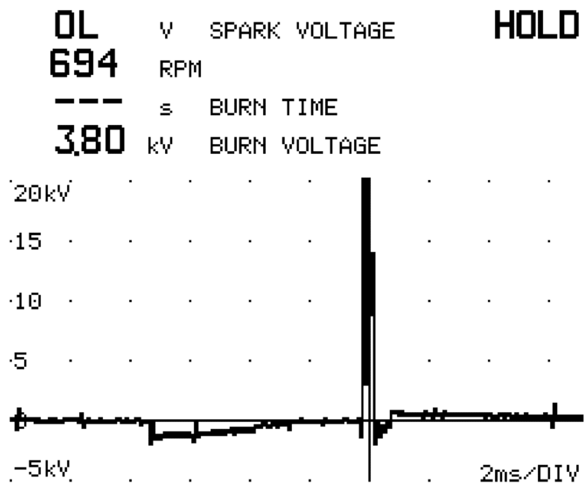
String Theory

If firing KV is smaller, there is more energy for spark duration to last longer



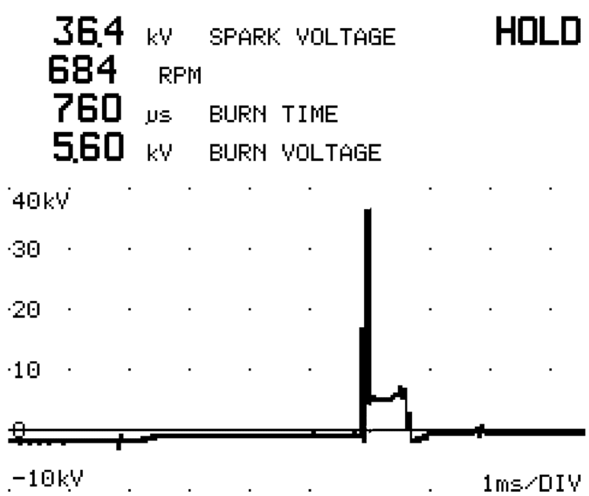
If firing KV is higher, there is less energy left over, so spark duration will be shorter.

(Both these strings are the same length.)



Open spark plug wire: This wire fell off the spark plug. See how the Firing KV (Spark voltage) went so high it's OL (out of limit) and the spark duration (burn time) is really tiny.

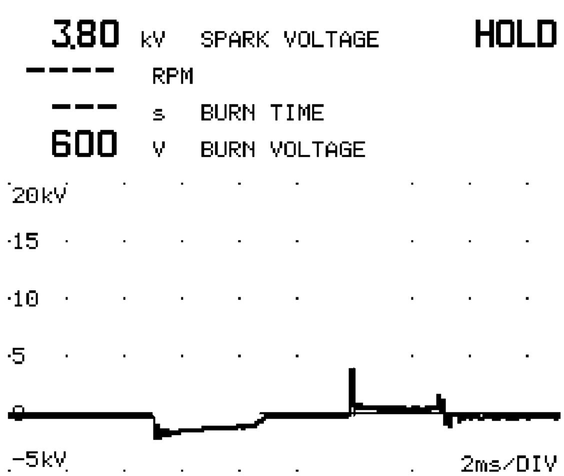
Good example of string theory—all the energy went into jumping the plug gap, no energy left to continue the burn time.



Another example of **high KV** (spark voltage) and short spark duration (burn time)

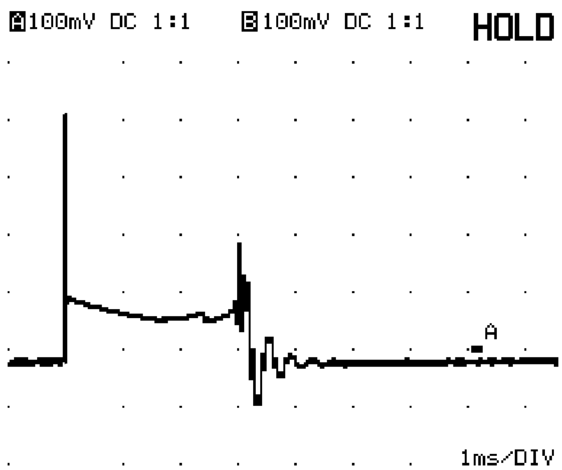
The firing KV is over 35, and so the spark duration is less than the normal 1-2 ms. It's only 0.7 ms. 760 us (microseconds) = 0.76 ms

When diagnosing this, look for **big gaps or high resistance problems.**



Low KV and long burn time are caused by **low resistance problems.** (This was a grounded spark plug wire.)

Notice spark duration is almost 3ms (more than 1-2ms) and firing KV is about 4KV, much lower than normal.



Another view of the grounded plug wire. At 100 mv/div, with a 10,000:1 probe, each division is only 1KV.

String Theory example: this ignition has only about 4 KV firing height, but a duration of almost 3 ms. (longer than normal)

Low Resistance: look for problems like grounded wires, low compression, or very rich air/fuel ratios.

This **10,000:1 probe** is the tool to pickup secondary ignition patterns.

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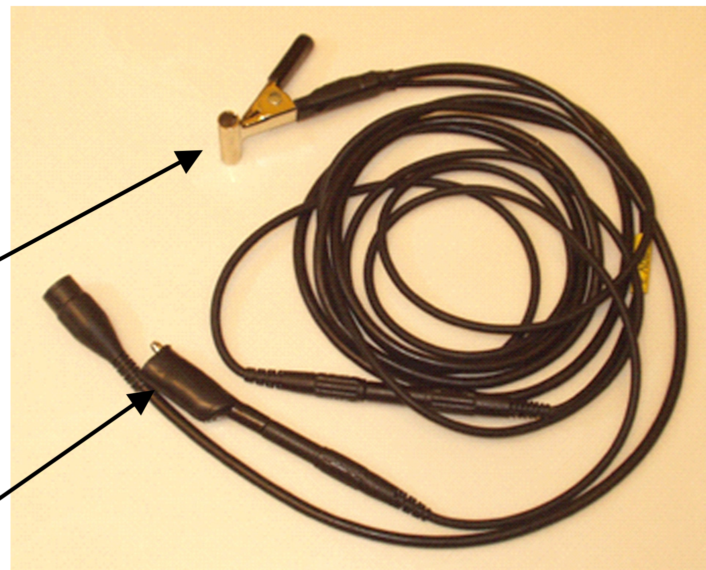
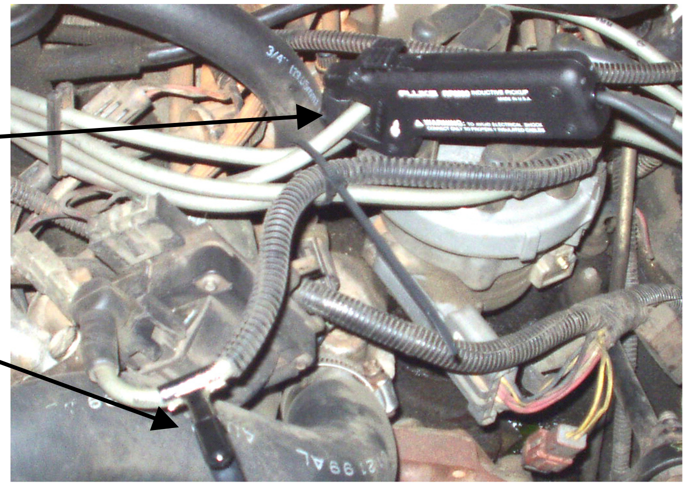
foil



To get secondary ignition readings on your scope, you need a secondary pickup. This will be either a **1000:1 probe, or 10,000:1 probe**. They aren't expensive, and they will let you see secondary ignition on any scope. You don't need a fancy scope, or one previously set up to see secondary ignition. You may need an adapter if you have to go from banana plugs to BNC connectors.

The Fluke 97 or 98 uses a 10,000:1 probe. When you use the automatic mode on the 98, the voltage range automatically shows correctly. So it shows the KV you are reading. If you are using the 97 or 98 on the scope mode, you can just do the calculations and figure that 1 volt represents 10,000 volts. Most other scopes use a 1000:1 probe. You just do the calculations to match. Then 1 volt equals about 1000 volts, or 8 volts would be 8 KV. The voltage doesn't always work out perfectly, but it can give you an idea. Be careful, the 1000:1 and the 10,000:1 probes look just the same. You might want to check your reading with another source to confirm your KV readings are right.

Secondary Hookup for a
conventional distributor system:



igger. Attach it to the spark plug
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probe takes the
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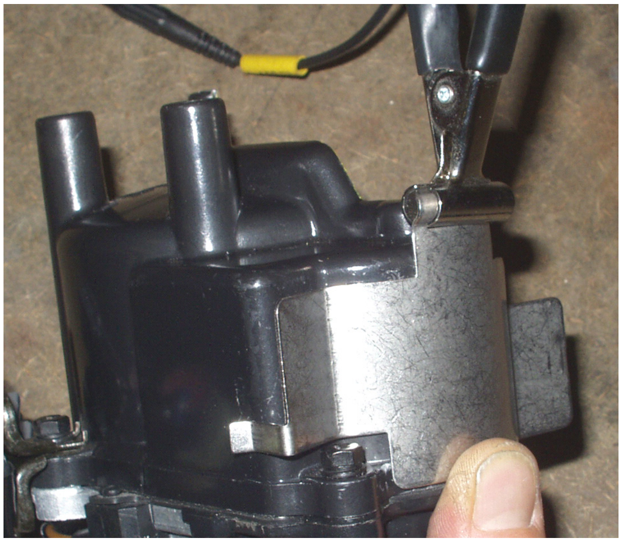
When you take secondary ignition readings, the **ignition pickup is the voltage sensor.** There are several things to keep in mind about this that will help you. The probe **will pick up voltage between the probe and the ground.** It will sense the voltage difference between the two. But that's all it will sense. It will not pick up voltage before the probe. For example, look at the diagram of secondary hookup above. What if there was high resistance where the coil wire attached to the coil. The coil wire could be corroded at the end. This would cause a very high firing KV and short spark duration. But the sensor wouldn't show abnormally high firing KV because that voltage drop is not between the probe and the ground. So your firing KV would look fine, but really it isn't, it's too high. But the spark duration (or burn time) would show the problem because it would be affected by the high voltage problem.

Another thing about how the ignition pickup acts as a voltage sensor. Sometimes the voltage is **not accurate because of different conditions** at the point of sensing. Some spark plug wires conduct their magnetism out to the surface differently than others. So the voltage will look different on some systems than others. Don't get too hung up about exactly what the voltages should be. You are looking for trends and clues. Those skinny Toyota plug wires are one example of wires that don't conduct the magnetism out as far as some other wires.

Also, what if you are **using an adapter** to lead the magnetism to the ignition pickup. This is a common thing to do for old GM distributors or newer Toyota or Honda distributors. These adapters work because the magnetism likes to flow through metal much better that it likes to flow through air. So an adapter that fits around where the magnetism is will help conduct the magnetism up to the 1000:1 or 10.000:1 probe. Just remember that some magnetism is lost by using the adapter, so the voltage sensed will not be all the voltage that is really there. You will see lower levels of voltage on your scope.



Using Adapters to pick up signals

When the **coil is inside the distributor**, you can use a metal adapter to “pull” the magnetism to your ignition pickup. But you loose some signal strength.

Foil Tape can be used to make an adapter. You wrap the foil over it, and twist one end to a nipple shape. Then attach the 1000:1 or 10,000:1 adapter to the foil nipple.

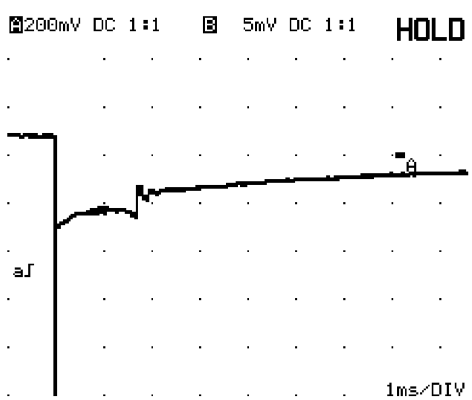
Read COP by making an adapter of foil tape

You can read secondary voltage off many COP coils by making your own adapter with foil tape (made for heating and air conditioning ducts.) It can help focus the magnetism so your ignition pickup can pick it up.

You can also **use foil tape as an adapter**. You can make your own adapter by using foil tape used for heating and air conditioning ducting. This is more than just duct tape. It looks like heavy aluminum foil with sticky stuff on one side. But it’s in a roll like duct tape. It’s available at hardware stores. This is cool, because you can wrap some of it near a COP coil you don’t have the adapter for, twist the end into a nipple to concentrate the magnetism into a point, and clip on your ignition pickup to this point. Now you can get a pattern. But some magnetism is lost by your home made adapter. So don’t expect the firing KV voltages to be exact. But the spark duration (burn time) will be accurate. That’s one of the nice things about using burn time for diagnosis. You can almost always read it one way or another. Some COP coils have the ignition module or igniter on top of the coil. This makes it harder to get the foil tape close enough to where the magnetism is. Just do the best you can. If you can’t get a good secondary ignition signal, you may still be able to get primary ignition voltage to see a signal. Or you may have to look at the end of the ignition amperage pattern for information from the turn-off spike.

The patterns we have used so far have all been what I call **“right side up”.** I mean, as the spark plug fires, the voltage spike points up. Most of us think this is normal, but we should talk about this a bit. We call this normal because all the ignition oscilloscope machines we have seen arrange the pattern this way. In reality, the conventional spark ignition spike goes negative. So it should point down, not up. Apparently, when the machines were being developed during World War II, the guys liked the pattern better if the spikes went up, so they inverted them so that’s how they went. And it became the normal way to do things.

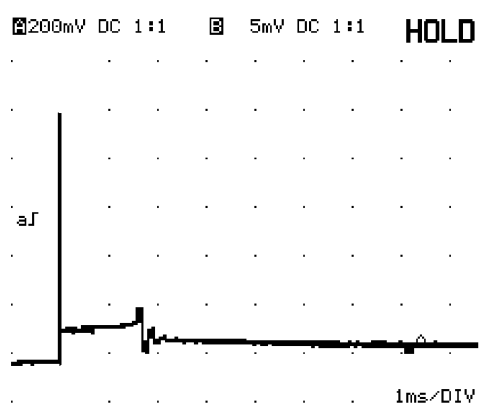
When you start looking at ignition patterns, you might find that your **pattern points down,** because your scope hasn’t done anything special to invert the pattern back to pointing up. You are looking at the true voltage direction. If you want to, you can invert the pattern so it looks “normal”. If your 1000:1 or 10,000:1 probe has banana plug connectors, you can switch them around. Put the “+” one in the “-“ hole, and the “-“ one in the “+” hole. That will change the polarity so it will invert the pattern. If you have BNC connectors, you might have to get double adapters for banana plugs so you do that switching. Some scopes, like the Flukes, have an option to invert right in the software. You just push a button. Don’t forget this up or down direction will make a difference when you choose the right trigger voltage, and where you position the zero on your screen.



Ignition spikes usually go down, but many analyzers and scopes invert the pattern so it looks “normal” and points “upright”.

When reading ignition, many of your patterns will naturally point down.

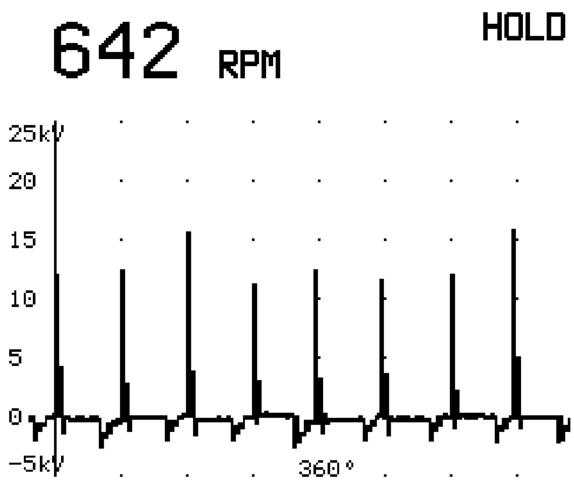
DIS ignition will have half the patterns spiking up, and half the patterns spiking down. When reading DIS patterns, adjust your zero position and trigger to get the pattern you need.



Understanding this invert problem comes in handy when you look at **DIS systems.** These are the ignition systems that have one coil firing two spark plugs through two different plug wires. (Some times called “waste spark” ignition systems.) When you look at the pattern on these systems: one will look “right side up” and one will look “up side down”. The problem is sometimes you can’t get the pattern on the screen at all because you

aren't set up correctly. If the spike goes down, but you are set up to look at a spike going up, your zero position will be too far down for you to see any thing, and the trigger voltage may be wrong so you have trouble getting the pattern in the first place. When looking at DIS ignition, you need to be able to move your zero point up and down to get the pattern. And sometimes you have to adjust the trigger above or below zero to get the pattern at all.

Parade Patterns: We have been showing only one cylinder at a time patterns. But scopes can be set up to show many cylinders at once. (Parade or Display patterns.) We can then compare firing KV from one cylinder to another. But you can't see enough information to compare burn time or spark duration.

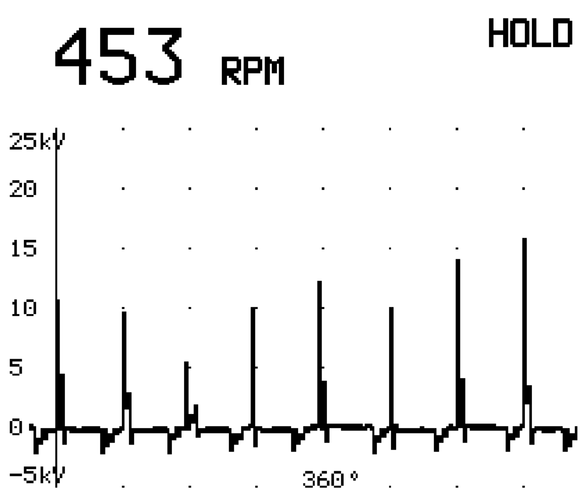


Normal engine, no problems

This Fluke 98 makes it easy to do a parade (display) pattern, but you can still do it with most scopes.

Note: some variation in KV firing height is normal.

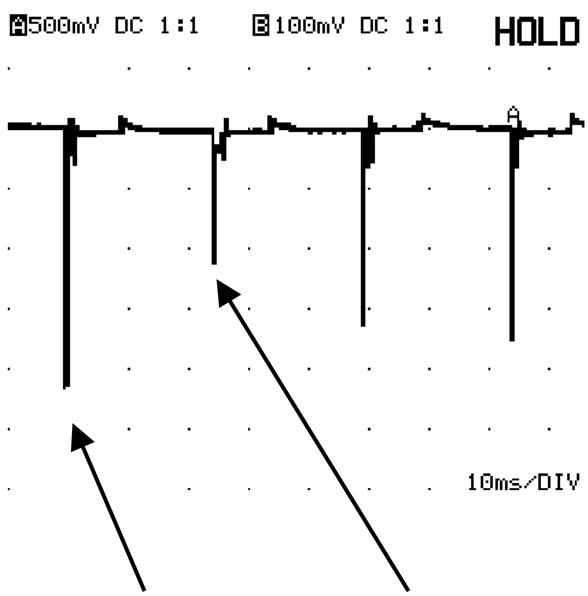
10,000:1 probe is at coil wire, and RPM sensor is at cylinder #1.



Low resistance problem on the third cylinder, that's **#4** in the firing order.

Since the RPM trigger probe is on #1, the pattern starts with cylinder 1. With a firing order of 1, 5, 4, 2, 6, 3, 7, 8, the third cylinder is #4.

Low firing KV of only 5 KV is a low resistance problem, like a grounded wire or no compression.



Parade pattern of 4 cylinder engine.

With only a 1000:1 or 10,000:1 probe for voltage at coil wire, and an RPM probe at cylinder #1 for trigger, you can get this pattern on a basic scope.

Pattern seems "upside down" because that's how the voltage normally goes.

Engine runs OK, but pattern shows a **high resistance -- big gap problem** developing on three cylinders, especially cylinder #1. (firing order is 1, 3, 4, 2) Spark plugs were really worn.

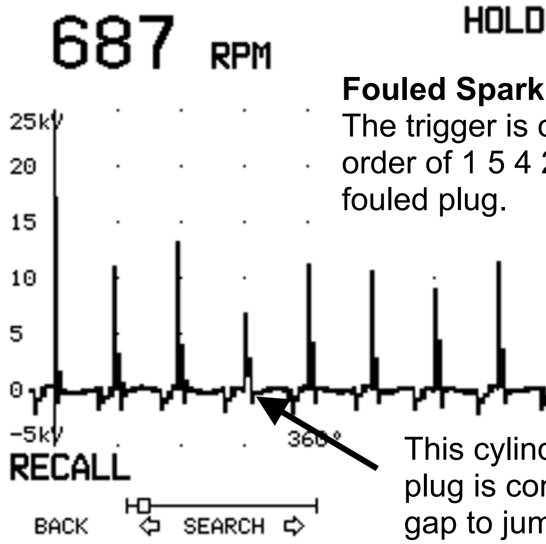
Cylinder #1 is about 22KV, #3 is about 12KV

A 10,000:1 probe shows 1 volt at the scope for 10,000 volts at the wires.

So 500 mV (0.5v) per division = 5 KV/div
This pattern is 12 to 22 KV

Let's talk about **Fouled Spark Plugs.** First, what do we mean by fouled? If the area around the tip is covered with something that could conduct electricity – like gas, oil, or carbon deposits – then the spark would not have to jump the gap to get to ground. The spark could just conduct through the oil to get to ground. And electricity, being lazy like you or me, only does as much work as it has to. It's hard to jump through a gap (all that insulating oxygen) and it's easier to just conduct through a substance to get to ground. So that's what it will do.

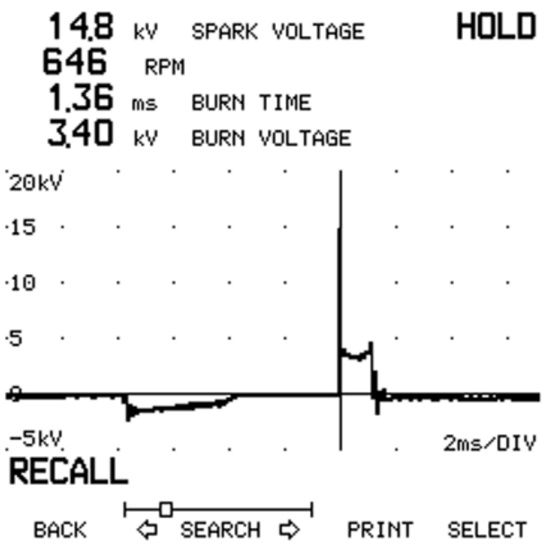
So **how will that look on a scope?** Since the firing KV is how much voltage is needed to jump across all the gaps, a fouled plug will have a **lower KV**. It doesn't have to jump the gap of the spark plug. If there is a distributor, with rotor and cap, it will only have to jump the gap of the rotor air gap. If there is a DIS waste spark coil, firing two spark plugs at once, it will only have to jump the gap of the spark plug that is not under compression. And that is easy, since there is not much air pressure there. If it a coil over plug (COP) system, there may not be much gap at all to jump through, so the KV will be small. The **burn time will often be longer**, because there is lots of energy left in the coil. It wasn't used up jumping across the gaps. But if the substance was some carbon that had a lot of resistance, because of how far the spark has to conduct through the carbon, then the burn time may not be that much longer because it takes a lot of energy to push through it.



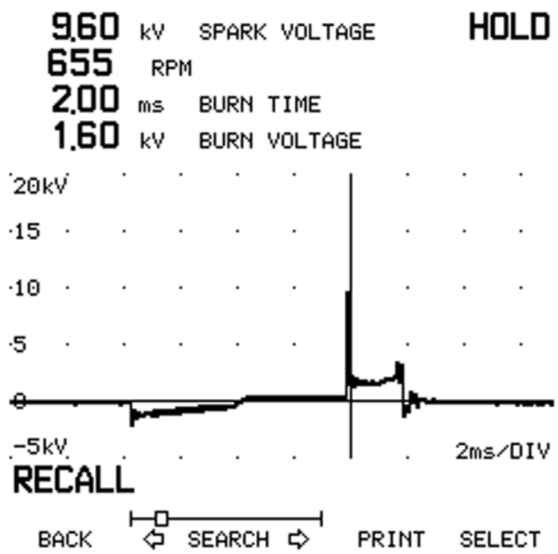
Fouled Spark Plug
The trigger is on cylinder #1, with a firing order of 1 5 4 2 6 3 7 8, it is #2 that has the fouled plug.

This cylinder is the fouled plug—oil on the spark plug is conducting the electricity so there is less gap to jump across

Looking at one cylinder at a time, you can see more detail. These are from the same Ford.



Normal spark with 14.8 KV and 1.36 ms burn time.



Fouled spark plug shows lower KV of only 9.6, but longer burn time of 2.0 ms

In summary, set-up the pattern correctly and you get gobs of information that will help you with diagnosis.

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